



Appendix D

In Situ Vitrification



Pre-Conceptual Designs of Various Alternatives for the V-Tanks
Rev. 0; November 2002

11-11-2002 10:00:00 AM





Appendix D

In Situ Vitrification

Utilities

- A 4500 kVA, 3-phase power supply, with a voltage range of 12.47- to 13.8-kV, and 200-A fuses on each power supply phase.

Consumables

- Twenty-four 6-ft long x 12-in. diameter graphite electrode sections, machined to allow connection, via machined graphite plugs
- Twelve machined-graphite plugs, capable of connecting the graphite electrode sections to each other
- 5-ft³ of graphite starter path material (two 21.5-ft X 5-ft X 0.5-in starter planes, plus additional material around electrodes)
- 60-ft of 14-in diameter PVC pipe (for electrode guide tubes)
- 16,000 kg of Aquaset, to stabilize the GAC-filtered decant liquid and collected condensate
- 925 kg of GAC
- 794 kg of SGAC
- 8330 kg of concrete to rock up the GAC and SGAC housings for disposal off-Site (GAC) or at ICDF (SGAC)
- A total of 234 55-gal drums, for disposal of the Aquaset-stabilized liquids (228 drums), the macro-encapsulated HEPA filters (4 drums) or the resulting phosphorus layer from the vitrified waste form (2 drums)
- 12 kg of caustic NaOH
- Twelve 10-yd³ boxes for PPE/debris disposal at ICDF.

Equipment Use

- Use of either the Liquid Retrieval System (from the Early Remedial Action) for decanting liquid from all-four V-tanks, prior to pumping out the tanks
- Use of a backhoe and excavator to: 1) place the graphite electrodes and starter planes; 2) dig up the soil needing to be added to the "to-be-vitrified" 10,000-gal tank; 3) dig up the soil needing to be added to the empty 10,000-gal tanks; and 4) digging up the fractured vitrified waste form and partially melted tank shells left, following in situ vitrification operations.
- Use of a 750-kVA transformer for ancillary equipment



-
- Use of a 3750-kVA Scott-Tee transformer, with at least 16 voltage taps (ranging from 4160 V to 400 V, corresponding to current capacities between 450 A and 4000 A, respectively)
 - Use of two saturable reactors, with their respective control windings, on the secondary side of the 3750-kVA Scott-Tee transformer, to control current and/or voltage being introduced to the electrodes
 - Use of emergency lighting for the portable vitrification unit
 - Use of portable personnel air instrumentation
 - Use of a 112-kVA transformer for supplying power to the process control station (and emergency lighting)
 - Use of a 750-kW diesel generator, to supply emergency power to all off-gas system components (in the event of a power outage). Actuation of the diesel generator shall be controlled by the batch logic sequencing in the process control station
 - Use of a propane supply tank capable of handling 74 std m³ of propane fuel
 - Use of a crane, for: 1) placement and removal of the off-gas hood; 2) attachment and suspension of the vibratory hammer over the vitrified waste form during fracturing; 3) removing large vitrified waste form pieces (and partially melted tank debris) from the excavation area; and 4) lifting out Tank V-9 (empty), following ISV processing
 - Use of four 20-yd³ roll-off boxes (22.83-ft long x ~7.5-ft wide x 4.71-ft tall, each) for disposal of the vitrified waste form residue and contaminated soil at the ICDF.

Equipment

- A 328-L (131 kg) GAC filter, for organic filtration of the decanted liquid
- An AEA pumping system, for transferring the V-tank residues (after decanting) from three of the tanks into the "to-be-vitrified" tank (Tank V-2)
- A stainless steel off-gas hood, with a bottom dimension spanning at least 55-ft X 41-ft, that is capable of being placed over the entire contents of the "to-be vitrified tank, plus the tank vents to the two adjacent 10,000 gal tanks., at the same time. The stainless steel hood should be designed to be capable of maintaining a vacuum equivalent to at least 1-in. (w.c). The stainless steel hood shall consist of a metal super-structure that is capable of withstanding temperatures up to 900°C, with 8-ft X 4-ft panels of stainless steel sheeting that can handle temperatures up to 550°C, without warping, and can be easily dismantled and stored. A non-welded (bolted) hood design should be used for placing the panels on the metal superstructure
- Use of an electrode feeding system, for inserting the graphite electrodes into the vitrified waste form
- >50 ft of >1-ft diameter stainless steel off-gas pipe
- An 80-kw Pre-heater, capable of raising 50 std m³/min of off-gas from 45°C to over 100°C
- A stainless steel-HEPA filter system, with blowback option, capable of handling a flow rate of 50 m³/min of off-gas (standard temperature and pressure), at temperatures up to 100°C. The proposed

design consists of a HEPA filter housing capable of housing four 2-ft X 2-ft X 1-ft deep HEPA filters (in parallel)

- A 6-ft X 12-ft contamination control tent, to be placed over the man-ways during vent enlargement
- A portable in situ vitrification unit consisting of the following:
 - A quencher-scrubber system, consisting of a quench-tower, a 2-stage tandem nozzle scrubber, and a mist eliminator. The quencher-scrubber system shall be capable of cooling 50 standard m³/min of off-gas air from temperatures of 150-350°C to temperatures of 70°C, while also scrubbing the off-gas for acid gases and condensable contaminants. Cooling water flow to the quench-tower shall be at a rate of 12 gpm, while water flow to the first- and second-phases of the scrubber shall be 24 gpm and 16 gpm, respectively. The mist eliminator shall be designed to remove water droplets greater than 12 µm from the off-gas. The condenser and mist eliminator shall be designed to transfer ~250 kW from the off-gas into the condensate system
 - A 12 gpm recirculating scrub pump, for pumping water to the quench tower
 - A 24 gpm recirculating scrub pump, for pumping water to the 1st-stage scrubber chamber
 - A 16 gpm recirculating scrub pump, for pumping water to the 2nd-stage scrubber chamber
 - A single-stage heat exchanger sized to remove up to 120 kW from the scrub solutions
 - A 3500-gal condensate collection tank, initially filled with 800 gal of clean scrubber water, and supplied tank agitation
 - A small caustic addition tank (< 30 L), for adding caustic NaOH to the collected condensate water, as necessary
 - A 1.4-m x 1.4-m x 1.0-m deep GAC filter system
 - A 1.4-m x 1.4-m x 1.0-m deep SGAC filter system
 - A blower capable of achieving 50 std m³/min at 90°C and -229 cm, w.c.
 - A backup blower for the portable off-gas trailer, rated for a capacity of 25 std m³/min, in the event of blower failure
 - A 15-kW off-gas heater, designed to heat 50 std m³/min of 70°C-off-gas to 82°C
 - A non-stainless steel-HEPA filter system, capable of handling a flow rate of 50 std m³/min of off-gas at 85°C. The HEPA system shall be designed similar to the stainless steel-HEPA filter system (a single housing, consisting of four 2-ft X 2-ft X 1-ft deep HEPA filters, in parallel)
 - Associated piping necessary to transfer the off-gas through the various off-gas components.
- A process control station, able to control pressure drop across the scrubber systems, blower inlet vacuum, off-gas differential temperature across the heater, negative pressure in the hood, and batch

logic sequencing of specific operations, in the event of equipment failure, while monitoring various components of the ex situ vitrification process

- A separate process control station for the electrode power supply system
- A stack sampling system, for monitoring oxygen, carbon monoxide, hydrogen chloride, radionuclide, and mercury emissions to the environment (downstream of 2nd-stage HEPA filter system)
- A high capacity (50 std m³/min.) off-gas thermal oxidizer, with minimal propane feed rate (8 Lpm)
- Shielding for the AEA piping (transferring the residual sludge material to the “to-be-vitrified” 10,000-gal tank)
- A 50-ft X 35-ft tent for excavating out (and fracturing) the vitrified waste form
- A vibrating hammer device for fracturing the vitrified monolith, during excavation activities
- Sheet piling, to be used on the soil excavation.



Appendix E

Ex Situ Vitrification



Pre-Conceptual Designs of Various Alternatives for the V-Tanks
Rev. 0; November 2002

CONFIDENTIAL - SECURITY INFORMATION





Appendix E

Ex Situ Vitrification

Equipment List

Utilities

- A 4500 kVA, 3-phase power supply, with a voltage range of 12.47- to 13.8-kV, and 200-A fuses on each power supply phase.

Consumables

- Twelve 4-ft long x 12-in. diameter graphite electrode sections
- 9-ft³ of graphite starter path material (18-ft X 4-in X 3-in, for each roll-off box)
- 24-ft of 14-in diameter PVC pipe (for electrode guide tubes)
- Six 20-yd³ roll-off boxes (22.83-ft long x ~7.5-ft wide x 4.71-ft tall, each), used for ex situ vitrification of the mixed soil and tank sludge residue
- 36 m³ of refractory materials used in the six roll-off boxes
- Plastic sheeting
- 13,420 kg of Aquaset, to stabilize the GAC-filtered decant liquid and collected condensate
- 800 kg of GAC
- 667 kg of SGAC
- 7107 kg of concrete to rock up the GAC and SGAC housings for disposal off-Site (GAC) or at ICDF (SGAC)
- 140 55-gal drums, for disposal of the Aquaset-stabilized liquids. (As an alternative, if stabilization of the liquids is performed after tank retrieval operations, the entire stabilized contents can be put into one of the 10,000 gal tanks, with room to spare, eliminating the need for 140 drums.)
- 10 kg of caustic NaOH
- Twelve 10-yd³ boxes for PPE/debris disposal at ICDF.

Equipment Use

- Use of the Liquid Retrieval System (from the Early Remedial Action) for decanting liquid from all-four V-tanks, prior to pumping out the tanks
- Use of a backhoe and excavator for digging up the 28 m³ of soil needed for mixing with the sludge (prior to vitrification, backfilling the roll-off boxes, and backfilling the holes left by excavation of the tanks)
- Use of a 750-kVA transformer for ancillary equipment



-
- Use of a 3750-kVA Scott-Tee transformer, with at least 16 voltage taps (ranging from 4160 V to 400 V, corresponding to current capacities between 450 A and 4000 A, respectively)
 - Use of two saturable reactors, with their respective control windings, on the secondary side of the 3750-kVA Scott-Tee transformer, to control current and/or voltage being introduced into the electrodes
 - Use of emergency lighting for the portable vitrification unit
 - Use of portable personnel air instrumentation
 - Use of a 112 kVA transformer for supplying power to the process control station (and emergency lighting)
 - Use of a 750-kW backup diesel generator, to supply emergency power to all off-gas system components (in the event of a power outage). Actuation of the diesel generator shall be controlled by the batch logic sequencing in the process control station
 - Use of a propane supply tank capable of handling 70 std m³ of propane fuel
 - Use of a crane, for excavation and removal of the empty V-tanks
 - Use of a stack sampling system, for monitoring oxygen, carbon monoxide, hydrogen chloride, radionuclide, and mercury emissions to the environment (downstream of 2nd-stage HEPA filter system).

Equipment

- A 328-L (131 kg) GAC filter, for organic filtration of the decanted liquid
- An AEA pumping system, for transferring the V-tank contents into the 20-yd³ roll-off boxes (with soil)
- A 25-ft X 35-ft contamination control tent, for roll-off box preparation (prior to ex situ vitrification)
- A stainless steel off-gas hood, with a bottom dimension spanning at least 23-ft X 16-ft, that is capable of being placed over two 20-yd³ roll-off boxes (22.83-ft long x ~7.5-ft wide x 4.71-ft tall, each), at the same time. The hood must be at least 8 ft high. The stainless steel hood should be designed to be capable of maintaining a vacuum equivalent to at least 1-in. (w.c). The stainless steel hood shall consist of a metal super-structure that is capable of withstanding temperatures up to 900°C, with 8-ft X 4-ft panels of stainless steel sheeting that can handle temperatures up to 550°C, without warping, and can be easily dismantled and stored. A non-welded (bolted) hood design should be used for placing the panels on the metal superstructure
- Four electrical connections for the graphite electrodes
- >50 ft of >1-ft diameter stainless steel off-gas pipe
- An 80-kw Pre-heater, capable of raising 50 std m³/min of off-gas from 45°C to over 100°C
- A stainless steel-HEPA filter system, with blowback option, capable of handling a flow rate of 50 m³/min of off-gas (standard temperature and pressure), at temperatures up to 350°C. The proposed

design consists of a HEPA filter housing capable of housing four 2-ft X 2-ft X 1-ft deep HEPA filters (in parallel)

- A portable ex situ vitrification unit consisting of the following:
 - A quencher-scrubber system, consisting of a quench-tower, a 2-stage tandem nozzle scrubber, and a mist eliminator. The quencher-scrubber system shall be capable of cooling 50 standard m³/min of off-gas air from temperatures of 350°C to temperatures of 40°C, while also scrubbing the off-gas for acid gases and condensable contaminants. Cooling water flow to the quench-tower shall be at a rate of 12 gpm, while water flow to the first- and second-phases of the scrubber shall be 24 gpm and 16 gpm, respectively. The mist eliminator shall be designed to remove water droplets greater than 12 µm from the off-gas. The condenser and mist eliminator shall be designed to transfer ~250 kW from the off-gas.
 - A 12-gpm recirculating scrub pump, for pumping water to the quench tower
 - A 24-gpm recirculating scrub pump, for pumping water to the first-stage scrubber chamber
 - A 16-gpm recirculating scrub pump, for pumping water to the second-stage scrubber chamber
 - A single-stage heat exchanger sized to remove up to 120 kW from the scrub solutions
 - A 1600-gal condensate collection tank, initially filled with 800 gal of clean scrubber water, and supplied tank agitation
 - A small caustic addition tank (< 30 L), for adding caustic NaOH to the collected condensate water, as necessary
 - A 1.35-m x 1.35-m x 1.0-m deep GAC filter system
 - A 1.35-m x 1.35-m x 1.0-m deep SGAC filter system
 - A blower capable of achieving 50 std m³/min at 90°C and -229 cm, w.c.
 - A backup blower for the portable off-gas trailer, rated for a capacity of 12.5 std m³/min, in the event of blower failure
 - A 15-kW off-gas heater, designed to heat 50 std m³/min of 40°C-off-gas to 52°C
 - A non-stainless steel-HEPA filter system, capable of handling a flow rate of 50 std m³/min of off-gas at 55°C. The HEPA system shall be designed similar to the stainless steel-HEPA filter system (a single housing, consisting of four 2-ft X 2-ft X 1-ft deep HEPA filters, in parallel).
 - Associated piping necessary to transfer the off-gas through the various off-gas components
- A process control station, able to control pressure drop across the scrubber systems, blower inlet vacuum, off-gas differential temperature across the heater, negative pressure in the hood, and batch logic sequencing of specific operations, in the event of equipment failure, while monitoring various components of the ex situ vitrification process
- A process control station for the electrode power supply system
- A high capacity (50 std m³/min.) off-gas thermal oxidizer, with minimal propane feed rate (8 Lpm)

-
- Shielding for the AEA piping (transferring the residual sludge material to the roll-off boxes) and the roll-off boxes themselves
 - A 50-ft × 35-ft tent for excavating out the contaminated soil and empty V-tanks
 - Sheet piling to be used on the soil excavation.

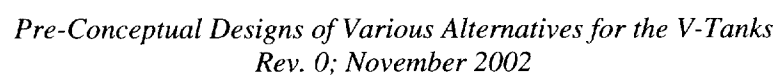


Appendix F

Vitrification Process Detailed Descriptions



Pre-Conceptual Designs of Various Alternatives for the V-Tanks
Rev. 0; November 2002





Appendix F

Vitrification Process Detailed Descriptions

F1. VITRIFICATION DETAILS

The following detailed descriptions of the in situ and ex situ vitrification processes and the components and equipment used in those processes assume that the reader is familiar with the overview descriptions presented in Section 3 of this document. The following material provides greater detail about the processes and equipment than is presented in Section 3.

F1.1 In Situ Vitrification Process Descriptions

Detailed descriptions of each of the major in situ vitrification (ISV) process components, as well as their sub-components and associated processes, are provided in the following paragraphs. These descriptions correspond to the process flow diagram shown in Figure 9, in the main body of this document, and the mass balance calculations included in Table 4 and Appendix C. A detailed equipment list for the proposed ISV operation is shown in Appendix D. The descriptions correspond to the twelve major components of the proposed ISV operation (see Section 3.4.4) and the summary waste disposition section for ISV (Section 3.4.5).

F1.1.1 Decanting Operation

The primary purpose of decanting the liquid is to remove as much water from the tank residues as possible before ISV processing. Based on discussions held with project personnel involved in the WAG 1 Early Remedial Action, it is assumed that this operation can be performed using the same equipment that has been designed for the Early Remedial Action.

This piece of equipment consists of a wand with holes located approx. 6 inches from the bottom of the wand. When the wand is inserted into a V-tank, the liquid supernatant surrounding the wand will run through the holes, into the bottom of the wand, without significant disturbance of the sediment layer. Once at the bottom of the sample wand, the supernatant will be slowly pumped to a collection tank at ground surface.

Original plans for the Early Remediation Action were to remove only 6000 gallons of liquid supernatant from Tank V-3. Upon questioning the INEEL designers of the equipment, it was determined that the liquid supernatant could be easily entrained to a depth 8 inches above the sediment phase layer without significant disturbance to the sediment layer. Furthermore, it was determined that even greater depths could be achieved if the decanting wand were gradually inserted to greater depths, with visual feedback of the bottom of the wand and the ability to reverse-pump the supernatant back into the tank. Discussion with cognizant technical personnel also confirmed that the supernatant was sufficiently clear in the V-tanks to allow such visual observation, with pump-reversal to occur, if necessary. On the basis of these discussions, it is safe to assume that a depth no more than 4 inches above the sediment layers in each tank can be obtained. The 4-inch attainable depth has been included in the mass balance calculations for this operation.



If this operation were selected, the decanting operation would most likely be carried out as part of the Early Remediation Action. Nevertheless, the cost and time associated with such an operation is included in our evaluation, since other proposed technologies may not benefit from removing increased volumes of supernatant from the tanks.

F1.1.2 Sludge Consolidation and Soil Feeding Operation

Liquid and sludge waste will then be transferred from tanks V-1, V-3, and V-9 to Tank V-2 using the AEA fluidic jet removal system. This system is capable of slurring and removing the sludge and liquid layers. The AEA system circulates the sludge and liquid by drawing the material into the system charge vessel and injecting it back into the tank at relatively high velocity. This “slurries” up loose material and dislodges materials that have caked or agglomerated in the vessel, producing a relatively uniform slurry waste stream that can then be transferred to Tank V-2 by diverting the charge vessel contents to the tank. The AEA system will be emptied back to the originating tank if necessary. The AEA system will be reactivated just before it is needed for pumping, to ensure re-suspension of any tank material that may have settled out in the interim.

The total sludge volume in Tank V-2 (after sludge consolidation) is approximately 2700 gal. This fills only 28% of Tank V-2. To provide safer ISV operations, it is necessary to fill the remainder of the tank with either contaminated soil (from the V-tank AOC) or material from the PM-2A tanks. The tanks will be filled using standard construction equipment. Because of the high water volume in the sludge, the total amount of soil to be added to the tank will be much greater than 7200 gal (more like 9900 gal). A substantial portion of the soil pore spaces will be filled with residual free liquid from the consolidated tank sludges.

Because of their proximity to Tank V-2, soil material will also have to be added to tanks V-1 and V-3 before Planar-ISV processing. Addition of this soil will also be performed using conventional construction equipment.

A major issue associated with the addition of soil to each of the 10,000-gal tanks is the limited access to the tank interior through a 20-inch diameter manhole. To facilitate soil addition to the tanks, the 20-inch manholes will be expanded to the diameter of the man-ways (6 ft) before adding soil to the tanks. Enlarging the man-ways will be performed using standard tank cutting techniques, under a contamination control tent.

F1.1.3 Starter Path Placement, System Connection, and Vitrification Operations

Starter path placement will be performed in the manner discussed in Section 3.4.1 of the report. The starter paths will be trenched using a suitably sized backhoe, with PVC pipe used as guides for the graphite electrodes, and a starter path of pressed graphite and glass frit used between the graphite electrodes in each trench. Placement of the starter paths at a depth adjacent to the top half of the tank has been proposed based on past Planar-ISV demonstrations on underground storage tanks.

The maximum targeted power level proposed for the Planar-ISV process is approximately 2880 kW. This power will be supplied via a 3750 kVA, 3-phase Scott-Tee transformer, with multi-tap voltage settings. The purpose of the Scott-Tee wiring is to convert 3-phase power into 2-phase power to provide balanced power to each of the graphite electrode pairs. The need for multi-tap settings, as previously

described, is due to the changing resistance of the batch vitrification process over time (resistance is inversely proportional to the diameter of the melt). The 3750 kVA system will be controlled via two saturable reactors, with their respective control windings, on the secondary side of the 3750 kVA transformer. The transformer will have 16 voltage taps, ranging from 4160 V to 400 V (corresponding to a maximum amperage rating of 450-4000 amps per phase, respectively).

In addition, a 750 kVA transformer is needed to supply power to the off-gas system and ancillary equipment. The 750 kVA transformer is connected to a 112 kVA transformer to supply power to the process control station.

Total power requirements for the ISV power unit are approximately 3700 kW. Power to these transformers should be via a three-phase electrical feed with a voltage range of 12.47-13.8 kV, with 200-A fuses on each phase of the electrical supply system.

Power to the system will be initiated at a ramp-up rate of approximately 50 kW/hr until the targeted power level (2680 kW) is reached. The operation will continue at this level for the remainder of the process, with periodic voltage tap-changes made as necessary. The total projected time for the Planar-ISV process is 153 hours.

The off-gases from the Planar-ISV process will be collected and directed to the ISV off-gas system by a suitable-sized stainless steel off-gas hood. The off-gas hood will be designed to be fire-resistant and capable of withstanding temperatures over 800°C. The off-gas hood will be sized to span the areal diameter of the 100°C soil isotherm surrounding an ISV melt. Based on past ISV melts, the maximum diameter of the 100°C isotherm is expected to be 8 feet from the melt. Based on the previous Planar-ISV test on a simulated 500-gal V-tank, the projected melt dimensions from processing a 10,000-gal tank will be 25-ft wide by 40-ft long. Therefore, the size of the oval-shaped off-gas hood must be greater than 41-X 56-ft in diameter.

Planar-ISV processing will proceed until the desired melt depth of 22-ft has been achieved (based on electrode depth) and thermocouples indicate that the entire top portion of Tank V-2 has been vitrified. Power will then be discontinued to the melt. The off-gas system will continue to operate for up to 24 hours after melting has been discontinued. During the entire operation, there should be no concern with pressure buildup within the tank. An additional advantage of the expanded man-way in Tank V-2 is the expanded capacity for venting of the V-tank during Planar-ISV processing. This expanded vent capacity minimizes the potential for pressure buildup due to evaporation of water and other volatile materials by the Planar-ISV process.

The pyrolyzing and dechlorinating nature of Planar-ISV applied to semi-volatile organic materials eliminates concerns over the vitrification process being considered similar to incineration. Since Planar-ISV's pyrolysis reactions occur in a subsurface, reducing environment, the reducing conditions do not favor the formation of dioxins and furans at the interface of the melt, as may occur with incinerators. For these reasons, the US Environmental Protection Agency considers Planar-ISV as a non-incineration thermal treatment process that is not subject to the same regulations as incinerators.

F1.1.4 High Efficiency Particulate Air (HEPA) Filtration of the Planar-ISV Off-Gas

Off-gases produced by the Planar-ISV process are expected to include substantial quantities of carbon monoxide (from incomplete combustion of the pyrolyzed gases), hydrogen chloride (from dechlorination of the semi-volatile organics and inorganic chlorides), volatile organics, steam, and mercury. In addition, the process is expected to produce small quantities of Cs-137 emissions (<0.3%) and even smaller quantities of entrained radionuclides. To keep the radioactive material from contaminating the ISV off-gas system, a primary stage HEPA filter system will be placed in front of the ISV off-gas system. The primary HEPA filter system will knock out 99.99% of the entrained particulate and cesium-137 released to the off-gas during Planar-ISV processing. Based on past history, the proposed system will consist of four 2-ft X 2-ft X 1-ft thick HEPA filters, housed in a large HEPA filter housing.

Because of the subsurface nature of the Planar-ISV process, it is possible that the resulting temperature of the off-gas stream in the hood, when mixed with air in-leakage, will be below the dew point at certain periods of the melt. As a result, there is a potential for condensation to occur in front of the HEPA filter, and plug the first-stage HEPA system. To prevent this from occurring, an 85-kW Super Heater should be placed in front of the HEPA filter system.

The HEPA system should be fabricated out of metal filters, and have a blow-back option, to send fines back to the melt. Use of such a blow-back system would minimize HEPA filter change-out during Planar-ISV operations, thereby minimizing the volume of HEPA filters to be disposed of.

With the subsurface nature of Planar-ISV, it is expected that the amount of entrained particulate will be much less than observed during conventional-ISV processes (typically less than 0.1 wt%). Nevertheless, the use of a blow-back potential is still desirable to counter any particulate collection efforts that may require HEPA filter change-out during Planar-ISV processing.

A second stage of HEPA filter system (along with a 15 kW off-gas pre-heater) is located downstream of the condenser unit, in front of the GAC and SGAC beds. The purpose of this filter is only to serve as a backup to the main HEPA filter system, in the event of its failure. Therefore, it is expected that this HEPA filter system will remain clean throughout the Planar-ISV process.

F1.1.5 Quenching, Scrubbing, Condensation and Mist Elimination from the ISV Off-Gas

The primary purpose of the quencher/scrubber/condenser/demistor unit is to scrub acid gases out of the off-gas system (to below MACT emission levels), while guaranteeing off-gas cooling to a temperature sufficient to absorb 100% of the residual VOCs and mercury on the GAC and SGAC beds. The proposed quencher/scrubber/condenser demistor unit is equivalent to the one used in similar Planar-ISV off-gas systems. It consists of:

- A quench tower cooled by 12 gpm water
- A two-stage Venturi scrubber, with 24 gpm water pumped to the first stage and 16 gpm water pumped to the second stage
- A heat exchanger capable of removing 120 kW from the scrubber liquids
- A condenser capable of removing 250 kW from the off-gas

-
- A 1600-gal condensate collection tank, with the capability of transferring 75% of the collected condensate tank volume.

Off-gases, which are typically at a temperature around 150°C (with spikes up to 350°C), are expected to be cooled to a temperature of 70°C before exiting the quencher/scrubber/condenser system. According to Henry's Law calculations, the scrubber/condenser unit should remove 98% of the acid gases (provided caustic is added to the condenser, to neutralize the acid gases), nearly 100% of the cadmium and arsenic, and approximately 34% of the water. The resulting condensate water will be added to an initial condensate volume of 3000 L, resulting in a total collected volume of 27.9 m³. Since there will be minimal mercury collection in the condensate waters, there is no need for further retorting of the collected condensate waters. The proposed demistor unit is a high efficiency mist eliminator, capable of removing all liquid particles, with droplet sizes over 12µm.

F1.1.6 GAC and SGAC Filter Systems

Following the second-stage HEPA system is a large GAC bed, immediately followed by a SGAC bed. The purpose of this two-stage activated carbon system is to initially remove all of the residual VOCs from the off-gas (on the GAC bed), followed by removal of the residual mercury vapors from the off-gas (on the SGAC bed). Both of these filter systems have been designed for a 2-second residence time. Previous studies by INEEL off-gas experts have shown that a 2-second residence time, with 3-mm diameter activated carbon, is sufficient to remove 100% of the residual VOCs and mercury from the off-gas, over operation periods of less than one month. At an off-gas flow rate of 50 std m³/min, and an operating temperature of 82°C, the total volume of each bed is 2.0 m³, with dimensions of 1.4-m x 1.4-m x 1.0-m thick. The rated pressure drops for such beds, at a flow rate of 100 ft/min (the maximum recommended flow rate), are approximately 5 inch w.c./foot of bed depth, or a 17 inch w.c., each (large but sufficiently sized for the 90 inch w.c. blower that is part of this system). The expected VOC saturation on the GAC bed is less than 10 wt%, while the expected mercury saturation on the SGAC bed is approximately 1 wt%. Both saturation levels are below the expected breakthrough concentrations of 14 wt%.

The GAC/SGAC system is designed to capture most of the VOCs on the GAC bed (with minimal mercury capture) and most of the mercury on the SGAC bed (with minimal VOC capture). Designing the system in this way will simplify the disposal options for both filters, since activated carbon filters with high organic concentrations (above 500 ppm) cannot be disposed of at ICDF, while activated carbon filters with high mercury concentrations would have to undergo thermal retorting, off-Site, prior to their macro-encapsulation.

In addition to these activated carbon beds there a 0.33 m³ GAC bed is used to filter organics from the decanted supernatant, prior to Aquaset solidification. The weight of GAC in this bed is calculated to be 131 kg.

F1.1.7 Thermal Oxidation System

On the backend of the ISV off-gas system is a propane-fueled thermal oxidation system. The primary purpose of the thermal oxidizer is to convert all residual carbon monoxide to carbon dioxide, so that the resulting off-gas system would qualify for MACT emission standards, if desirable. However, the thermal oxidizer also acts as an off-gas polishing system, for non-regulated noxious gases (such as

hydrogen sulfide) and a back-up system for the activated carbon beds (in the event of organic breakthrough). Therefore, it should not be considered similar to incineration, which burns the primary waste streams, as opposed to the treated off-gas streams from a pyrolysis system. Placing the thermal oxidation system on the downstream side of the blower allows for the benefits of thermal oxidation, without the need to manage the increased gas volume.

The fuel requirements for the thermal oxidizer are 8 L/min. Over a processing period of 153 hours, this amounts to 74 m³ of propane.

F1.1.8 Solidification of the Secondary Waste Liquids

The total volume of decanted liquid collected, prior to Planar-ISV processing, is 12 m³. The total volume of condensate liquid resulting from the Planar-ISV process is 27.9 m³. Both of these liquids are to be stabilized via Aquaset, in 55-gal drums. Aquaset is designed to solidify liquid wastes, without mixing or significant volume increase. Furthermore, indications are that the resultant product will meet LDRs for all regulatory materials (primarily mercury) that are present in the liquid, post-GAC filtration. The solidification process will involve 45 gal of liquid placed in each 55-gal drum, along with 150 lb of Aquaset.

F1.1.9 Cementation of the Activated Carbon Filter Housings

According to INEEL Regulatory experts, the spent activated carbon filters can be classified and disposed of as debris, provided the activated carbon contents are maintained in their respective housings. To prepare the housing for eventual macro-encapsulation as debris waste, it is necessary to cement the activated carbon within their housings, prior to shipment to ICDF (SGAC) or Envirocare (GAC). Plans are to use a micro-fine cement to accomplish this.

F1.1.10 Fracturing of the Vitrified Monolith

After allowing sufficient time for cooling (approximately 1 yr) the vitrified monolith will need to be fractured into smaller pieces, as part of the overall excavation process. Glass fracturing will be performed using a vibratory hammer system, suspended from a crane. Based on previous tests conducted by Geosafe, glass fracturing can be accomplished at a cost of \$10-15/yd³. This does not include purchase of the vibratory hammer system, however.

F1.1.11 Excavation of the Contaminated Soil, Metal Tank Shells, & Vitrified Waste Form

Excavation of the V-tank area of concern will be performed using standard construction equipment (backhoes, cranes, excavators, etc.). During excavation, plans are to place a large tent structure over the dig-face, for contamination control purposes.

F1.1.12 Transportation and Disposal Operations

The contaminated soil and fractured melt will be transported to the ICDF via 20-yd³ roll-off boxes, and dumped at the ICDF. The tank shell remnants will be cut in half (via arc-cutting) with the respective shells loaded on trucks, for unpackaged shipment and disposal at the ICDF. The drums of solidified liquid, phosphate material, and macro-encapsulated HEPA filters will also be delivered to the ICDF, via

trucks, along with cemented SGAC filter housings and large wooden boxes of secondary waste debris (PPE, non-recoverable equipment, consumable materials). The cemented GAC filters will be shipped off-Site to Envirocare, via truck.

F1.1.13 Disposition Pathways

Upon completion of the vitrification process, the total volume of vitrified waste produced is 165 m^3 . After allowing sufficient time to cool (approximately 1yr), the vitrified monolith will be fractured into pieces, placed in roll-off boxes, and loosely disposed of at the ICDF, without packaging. Approval for this disposal was based on informal communications held between the ISV Principal Investigator and the cognizant regulatory person for the ICDF. Included in this vitrified waste form will be a 0.95 m^3 piece of steel that can also be disposed of at the ICDF, without packaging.

In addition, the ISV process is expected to produce approximately 0.31 m^3 of a phosphate layer, on top of the glass. Plans are to recover the phosphate layer from the glass during glass excavation, with the phosphate layer placed in two 55-gal drums, and disposed of at ICDF. The contaminant concentration within this phosphate layer is expected to be negligible.

Secondary wastes associated with the ISV process include the decanted supernatant, the collected condensate water, the off-gas GAC and SGAC housings, and the GAC filters used to remove organics from both the decanted supernatants and collected condensates. In addition, spent HEPA filters from the first-stage HEPA filter system will need to be disposed of as debris, along with all non-recoverable equipment personal protective equipment (PPE), and consumable materials.

The liquid supernatant and collected condensate waters will be solidified with Aquaset, prior to disposal. Use of Aquaset is expected to solidify the contents of the liquid materials, without significant increases in volume. In addition, solidification of liquids containing minor quantities of solids (such as are present in the decanted supernatant and collected condensate) can be solidified, via Aquaset, without the need for mixing or agitation. The Aquaset is simply added to the liquid. Vendors supplying Aquaset (i.e., Fluid Tech International) claims that 45-48 gal of liquid, placed within a 55-gal drum, can be solidified with 100-150 lb of Aquaset, with room to spare within the 55-gal drum. For purposes of calculation, an assumption of 150 lb Aquaset being added to 45-gal of liquid within each 55-gal drum was used. Based on this calculation, the total amount of 55-gal drums needed for stabilization of the decanted supernatant and collected condensate is 228 drums (assuming that 7 drum equivalents can be placed in Tank V-9, after it is excavated). The total amount of Aquaset needed for stabilization is 16,000 kg. The Aquaset is expected to bind up any non-organic contaminants within the liquids, such that the stabilized waste form does pass Land Disposal Restrictions (LDRs). In addition, according to mass balances prepared for this process, the total amount of mercury collected in the condensate waters and decanted liquids should remain below 260 ppm at all times, eliminating the need for retorting, prior to disposal. Plans are to dispose of the solidified liquids in 55-gal drums, at the ICDF.

To guarantee that the solidified liquid does not contain any hazardous organics (which could cause the waste to not meet LDRs), the decant liquid will be filtered with GAC, prior to solidification. The amount of GAC needed for this filtration operation is based on a total saturation content of 10-wt% prior to breakthrough, and a required GAC residence time of 1 min. Both pieces of data are taken from discussions with a GAC filtration expert. In fact, data from the NWCF Mercury Removal Feasibility Study (INEEL/INT-2000-00359) indicate that GAC organic breakthrough is not experienced until it



becomes 14 wt% saturated with organics. The total calculated volume of GAC filtration needed for the decanted supernatant is 131 kg. This is equivalent to 0.33 m³, assuming a density of 0.4 kg/L. Since mass data indicates no condensation of organics, there are no plans for GAC filtration of the collected condensate liquid.

In contrast with the GAC filtration of the decant liquid, the off-gas GAC filters and SGAC filters are designed for a residence time of at least 2 seconds, each. This is based on data from INEEL GAC filtration experts indicating that greater than 99.9% organic/mercury removal can be obtained from the GAC/SGAC filters at this residence time. Although off-gas GAC/SGAC filters also have concerns over absorbent saturation, the high volume of off-gas flow used in the Planar-ISV process makes the issue of residence time the dominant factor used in designing the GAC/SGAC filters. The total off-gas filters needing to be disposed of weigh 794 kg apiece (equivalent to a volume of 2.0 m³ apiece).

According to INEEL regulatory personnel, the treated GAC/SGAC filters can be cemented within their housings, then macro-encapsulated and disposed of as debris. As a result, following their use, the GAC and SGAC filter housing will be removed from their respective operating systems, and the contents of GAC or SGAC material within each housing will be cemented internally. The cemented GAC filters will then be shipped off-Site to Envirocare, for macro-encapsulation and disposal as debris. The cemented SGAC filter housings will be sent to ICDF, for macro-encapsulation and disposal as debris. The ultimate disposition of these two filter types is based on the assumption that minimal mercury is absorbed in the GAC filters, while minimal organics are absorbed on the SGAC filters. The total quantity of concrete needed for cementation is 8330 kg.

Other secondary wastes include the HEPA filters from the first-stage HEPA filter system (which will be macro-encapsulated in 55-gal drums, used PPE, consumable materials, and non-recoverable off-gas equipment. All of this material will be disposed of as debris at the ICDF, within twelve 10-yd³ waste disposal boxes.

The total volume of primary waste produced by the Planer-ISV process is 2,253 m³. Included in this volume are 14.8 m³ of solidified decant liquid, 165 m³ of vitrified waste form, 3.6 m³ of metal piping and tank shells, and 2,070 m³ of contaminated soil. The vitrified waste form will be disposed of at the ICDF, along with the metal remnants of Tanks V-1 and V-3 and the remaining volume of contaminated soil that was not vitrified by the ISV process. Plans are to perform waste disposal approximately one year after vitrification is complete to allow sufficient time (6-12 months) for the vitrified waste form to cool.

The total volume of secondary waste expected to be produced by the complete ISV process is 128 m³. This includes a disposed equipment volume of 83.5 m³, a solidified condensate volume of 34.2 m³, a GAC volume of 2.3 m³, a SGAC volume of 2.0 m³, and a macroencapsulated HEPA filter volume of 0.8 m³. The secondary waste volume is based on the assumption that all equipment coming in contact with the tank waste and off-gas will have to be thrown away as radioactive-waste. In addition, it is assumed that there will be no consolidation of the waste, via placement in containers, or cutting or crushing. It is felt that the actual secondary waste volume associated with this process can be substantially reduced if efforts are made to recover equipment (via D&D operations) and actual waste can be consolidated, cut, or crushed, prior to disposal.

F1.2 Ex Situ Vitrification Process Descriptions

Detailed descriptions of each of the major batch ESV components, as well as their sub-components and process descriptions, are provided in the following subsections. They correspond to the process flow diagram shown in Figure 10 in the body of this document, and the mass balance calculations included in Table 6 and Appendix C. A detailed equipment list for the proposed ESV operation is shown in Appendix E. The descriptions correspond to the thirteen major components of the proposed batch ESV operation (see Section 3.5.3) and the summary waste disposition section for batch ESV (Section 3.5.5).

F1.2.1 Decanting Operation

The primary purpose of decanting the liquid is to remove as much water from the tank residues as possible before ESV processing. Based on discussions held with project personnel involved in the WAG 1 Early Remedial Action, it is assumed that this operation can be performed using the same equipment that has been designed for the Early Remedial Action.

This piece of equipment consists of a wand with holes located approx. 6 inches from the bottom of the wand. When the wand is inserted into a V-tank, the liquid supernatant surrounding the wand will run through the holes, into the bottom of the wand, without significant disturbance of the sediment layer. Once at the bottom of the sample wand, the supernatant will be slowly pumped to a collection tank at ground surface.

Original plans for the Early Remediation Action were to remove only 6000 gallons of liquid supernatant from Tank V-3. Upon questioning the INEEL designers of the equipment, it was determined that the liquid supernatant could be easily entrained to a depth 8 inches above the sediment phase layer without significant disturbance to the sediment layer. Furthermore, it was determined that even greater depths could be achieved if the decanting wand were gradually inserted to greater depths, with visual feedback of the bottom of the wand and the ability to reverse-pump the supernatant back into the tank. Discussion with cognizant technical personnel also confirmed that the supernatant was sufficiently clear in the V-tanks to allow such visual observation, with pump-reversal to occur, if necessary. On the basis of these discussions, it is safe to assume that a depth no more than 4 inches above the sediment layers in each tank can be obtained. The 4-inch attainable depth has been included in the mass balance calculations for this operation.

If this operation were selected, the decanting operation would most likely be carried out as part of the Early Remediation Action. Nevertheless, the cost and time associated with such an operation is included in our evaluation, since other proposed technologies may not benefit from removing increased volumes of supernatant from the tanks.

F1.2.2 Roll-Off Box Preparation

Prior to sludge addition, the roll-off boxes will have to be lined with refractory material. In addition, thermocouples will need to be placed, soil will need to be added to the box, and the starter path material and graphite electrode sections will need to be placed. The refractory lining of each roll-off box is performed by placing a thermal insulation board on the bottom of the roll-off box, then placing a layer of silica sand over the insulation board. A slip form that is used to facilitate placement of side insulating material will then be centered in within each roll-off box. Insulating board and silica sand will then be

placed in the annular space between the slip form and the sides of the roll-off box. Plastic sheeting will then be used to line the interior of the centered slip form.

Following placement of the plastic sheeting, the pre-determined amount of soil will be placed into each roll-off box. A graphite starter path, consisting of a mixture of graphite and glass frit will be placed within 6 inches of the top of the placed soil. In addition, two 12-inch diameter graphite electrode sections will be vertically placed in the waste box, such that they come in electrical contact with the graphite starter path. The electrode sections need to be placed at a distance similar to the prescribed distance for the electrode feeders in the ESV off-gas hood. Upon completing this step, the slip form between the added soil and refractory lining can be removed.

F1.2.3 Shielding and Contamination Control Preparation

Due to the radionuclide content on the tank contents, adequate shielding and contamination control systems will be prepared and installed before sludge addition. This involves the placement of concrete or lead shielding over the AEA transfer line and around the prepared roll-off boxes. In addition, the placement of the sludge in the two roll-off boxes will be performed as remotely as possible, using robotic manipulation equipment and video cameras.

Contamination control systems will also be prepared for transferring the sludge into the roll-off boxes. The issues of contamination control are significantly minimized by the liquid (i.e., not dry) nature of the sludge. Therefore, the primary issues associated with contamination control is to prevent the AEA system from splashing the sludge out of the roll-off box. This can be done by pumping the AEA system to a closed, shielded reservoir tank, and draining the tank to the roll-off boxes using gravity. A contamination control tent will also be placed over the roll-off boxes during sludge transfer.

F1.2.4 Sludge Transfer

Residual supernatant and sediment phases from each V-tank will then be pumped to six 20-yd³ roll-off boxes, two roll-off boxes at a time, using the AEA fluidic jet removal system and the previously described tank reservoir. This system is capable of homogenizing and pumping the entire sediment and liquid phases from each V-tank. The AEA System circulates the sludge and liquid by drawing the material into the system charge vessel and injecting it back into the tank at relatively high velocity. This “slurries” up loose material and dislodges materials that may have become caked or agglomerated in the vessel, producing a relatively uniform slurry waste stream that can then be transferred (in batches) by diverting the charge vessel contents to the roll-off boxes. The AEA system will be emptied back to the originating tank after the desired amount of tank sludge has been placed in each roll-off box. The AEA system will then be reactivated just before it is needed for another batch makeup, to ensure re-suspension of any tank material that may have settled out in the interim.

According to detailed mass balance calculations, the entire contents of Tanks V-1, V-2, V-3, and V-9 can be placed into 1.5, 0.7, 1.6, and 1.6 roll-off boxes, respectively (with the necessary soil addition). This totals up to 5.4 roll-off boxes. Since six roll-off boxes will be used in this operation, this means that the roll-off boxes only need to be filled to approximately 90% of their capacity. Because of the varying sludge volume requirements from each tank, this will require some roll-off boxes to contain sludge portions from two different tanks. Based on the detailed mass balances, it appears that the differences in composition and water content for each V-tank is not sufficient to cause any problems with mixing tank

sludges. Current plans are to place Tank V-1's contents in 1.5 roll-off boxes, Tank V-2's contents in 0.75 roll-off boxes, Tank V-3's contents in 1.75 roll-off boxes, and Tank V-9's contents in 2 roll-off boxes (+/-0.16 roll-off boxes, each tank).

The AEA system will then pump a pre-determined amount of the tank sludge to a shielded reservoir tank. The reservoir tank will then be operated as required to flow the sludge over the top of the soil in each roll-off box, being careful to not disturb the starter path. Free liquids within the sludge will simply migrate through and become absorbed in the soil layer beneath the sludge.

F1.2.5 System Connection and Vitrification Operations

Following roll-off box preparation (performed two roll-off boxes at a time), power cables will be connected to each electrode. These power cable ends will be connected to electrical isolators within the off-gas hood. The tent will be removed from over the roll-off boxes, and the hood will be lifted by the crane and placed over the roll-off boxes. Insulated cable from the exterior isolators on the off-gas hood will then be connected to the power transformer and necessary off-gas connections will be adjusted.

The maximum-targeted power level proposed for the batch-ESV process is only 580 kW (due to the reduced size of the vitrification volume). Nevertheless, the uncertainty of this calculation makes it imperative that a large power system be available. For purposes of estimation, it is assumed that the same power supply that is used on the Planar-ISV system will also be used on the batch-ESV system. Therefore, the power for the batch-ESV system will be supplied via a 3750 kVA, 3-phase Scott-Tee transformer, with multi-tap voltage settings. The purpose of the Scott-Tee wiring is to convert 3-phase power into 2-phase power to provide balanced power to each of the graphite electrode pairs. The need for multi-tap settings has been previously described as due to the changing resistance of the batch vitrification process over time (resistance is inversely proportional to the diameter of the melt). The 3750 kVA system will need to be controlled via two saturable reactors, with their respective control windings, on the secondary side of the 3750 kVA transformer. The transformer will have 16 voltage taps, ranging from 4160 V to 400 V (corresponding to a maximum amperage rating of 450-4000 amps, per phase, respectively). In addition, a 750-kVA transformer is needed to supply power to the off-gas system and ancillary equipment. The 750-kVA transformer is connected to a 112-kVA transformer, for supplying power to the process control station.

Total power requirements for the ESV power unit are approximately 1400 kW. Power to these transformers should be via a three-phase electrical feed in the voltage range of 12.47-13.8 kV, with 200-A fuses on each phase of the electrical supply system. Power will be initiated to the system at a ramp-up rate of approximately 50 kW/hr, until the targeted power level (450-550 kW) is reached. The operation will continue at this level for the remainder of the test, with periodic voltage tap-changes made, as necessary. The total projected time for each batch-ESV process (two roll-off boxes per batch) is less than 48 hours.

During processing, the off-gases from the batch-ESV process will be collected and directed to the off-gas system via a suitable-sized stainless steel off-gas hood. The off-gas hood will be designed to be fire-resistant, and able to withstand temperatures over 800°C. The size of the off-gas hood should be designed to span and enclose two 20-yd³ roll-off boxes at a time. Based on a 23-ft long × 7.5-ft wide × 5-ft tall dimension for each 20-yd³ roll-off box, the size of the rectangular-shaped off-gas hood must be at least 16-ft on the short dimension, 24-ft on the long dimension, and over 6-ft tall.

Batch-ESV processing will proceed until the thermocouples at the edge of the melt indicate that the entire batch volume has been vitrified. Power will then be discontinued to the melt. The off-gas system will continue to operate for up to 24 hours after melting has been discontinued, while maintaining the roll-off boxes in the hood. During this cooling period, the next two roll-off boxes can be prepared. After 24 hours of cooling, the hood will be opened, the roll-off boxes containing vitrified material will be removed, and the freshly prepared roll off boxes should be placed into the hood. Power can then be re-initiated (again, going through a start-up period where power is increased at a rate of 50 kW/hr).

During each batch-ESV operation, there should be minimal concern with pressure buildup within the roll-off boxes. Even if pressure buildup is a problem, however, the relatively shallow nature of the batch-ESV process negates any potential for substantial pressure buildups that could cause vitrified material to be ejected from the hood.

The pyrolyzing and dechlorinating nature of batch-ESV, towards semi-volatile organic materials, eliminates concerns over the vitrification process being considered similar to incineration. Since batch-ESV occurs in a reducing environment, the conditions do not favor the formation of dioxins and furans at the interface of the melt, as may occur with incinerators. For these reasons, the US Environmental Protection Agency considers batch-ESV as a non-incineration thermal treatment process that is not subject to the same regulations as incinerators.

F1.2.6 High Efficiency Particulate Air (HEPA) Filtration of the Batch-ESV Off-Gas

Off-gases produced by the batch-ESV process are expected to include minor quantities of carbon monoxide (from incomplete combustion of the pyrolyzed gases), along with hydrogen chloride (from dechlorination of the semi-volatile organics and inorganic chlorides), volatile organics, steam, and mercury. In addition, the process is expected to produce small quantities of Cs-137 emissions (<0.3%), and even smaller quantities of entrained radionuclides (<0.1 wt%). To keep the radioactive material from contaminating the ESV off-gas system, it is desired to put a primary stage HEPA filter system in front of the ESV off-gas system. The primary HEPA filter system will knock out 99.99% of the entrained particulate and cesium-137 that is released to the off-gas during batch-ESV processing. Based on past history, the proposed system will consist of four 2-ft × 2-ft × 1-ft thick HEPA filters, housed in a large HEPA filter housing.

During initial startup, it is possible that the resulting temperature from the off-gas stream in the hood, when mixed with air in-leakage, will be below the dew point, at certain periods of the melt. If this were to occur, there is a potential for condensation to occur in front of the HEPA filter, sufficient to plug the first-stage HEPA system. To prevent this from occurring, an 85-kW Super Heater will be placed in front of the HEPA filter system.

The HEPA system should be fabricated out of metal filters, and have a blowback option, to send fines back to the melt. Use of such a blowback system would minimize HEPA filter change-out during batch-ESV operations, thereby minimizing the volume of HEPA filters needing to be disposed of.

A second stage of HEPA filter system (along with a 15-kW off-gas pre-heater) is located downstream of the condenser unit, in front of the GAC and SGAC beds. The purpose of this filter is only to serve as a backup to the main HEPA filter system, in the event of its failure. Therefore, it is expected that this HEPA filter system will remain clean throughout the batch-ESV process.

F1.2.7 Quenching, Scrubbing, Condensation & Mist Elimination from the ESV Off-Gas

The primary purpose of the quencher/scrubber/condenser/demister unit is to scrub acid gases out of the off-gas system (to below MACT emission levels), while guaranteeing cooling of the off-gas to a temperature sufficient to absorb 100% of the residual VOCs and mercury (on the GAC and SGAC beds). The proposed quencher/scrubber/condenser demister unit is equivalent to the one used in similar batch-ESV off-gas systems. It consists of:

- A quench tower cooled by 12 gpm water
- A two-stage Venturi scrubber, with 24 gpm water pumped to the first stage and 16 gpm water pumped to the second stage
- A heat exchanger capable of removing 120 kW from the scrubber liquids
- A condenser capable of removing 250 kW from the off-gas
- A 1600-gal condensate collection tank, with the capabilities of transferring 75% of the collected condensate tank volume.

Off-gases, which are typically at temperatures between 150°C and 350°C, are expected to be cooled to a temperature of approximately 40°C, before being passed downstream. According to Henry's Law calculations, the scrubber/condenser unit should remove 98% of the acid gases (provided caustic is added to the condenser, to neutralize acid gases), 100% of the cadmium and arsenic, and 14-41% of the water (depending on the residual amount of water left in each tank). The resulting 2.7 m³ of collected condensate will be added to an initial condensate volume of 3.0 m³, resulting in a total collected volume of 5.7 m³. According to mass balance calculations, no mercury should be collected in the condensate stream. As a result, there is no need to retort the collected condensate stream, prior to solidification of the condensate liquid. The lack of organic condensation (based on mass balance calculations) also eliminates the need for activated carbon filtration, prior to condensate solidification. The proposed demister unit is a high efficiency mist eliminator, capable of removing all liquid particles, with droplet sizes over 12µm.

F1.2.8 GAC and SGAC Filter Systems

Following the second-stage HEPA system is a large GAC bed, immediately followed by a SGAC bed. The purpose of this two-stage activated carbon system is to initially remove all of the residual VOCs from the off-gas (on the GAC bed), followed by removal of the residual mercury vapors from the off-gas (on the SGAC bed). Both of these filter systems have been designed for a 2-second residence time. Previous studies by INEEL off-gas experts have shown that a 2-second residence time, with 3-mm diameter activated (or sulfur-impregnated carbon), is sufficient to remove 100% of the residual VOCs and mercury from the off-gas, over operation periods of less than one month. At an off-gas flow rate of 50 std m³/min, with an expected GAC/SGAC temperature of 52°C (12°C over the post-condenser off-gas temperature), the total required volume for each activated carbon bed (GAC and SGAC) is 1.82 m³. The expected dimensions of each bed are 1.35-m x 1.35-m x 1.0-m thick. The rated pressure drops for each bed, at a flow rate of 100 ft/min, are approx. 5 inch w.c./foot of bed depth, or a 17 inch w.c., each (large but sufficiently sized for the 90 inch w.c. blower that is part of this system) The expected VOC saturation on the GAC bed is less than 10 wt%, while the expected mercury saturation on the SGAC bed is only 0.5 wt%. Both saturation levels are well below the expected breakthrough concentration of 14 wt% for both the GAC and SGAC beds.



The GAC/SGAC system is designed to capture most of the VOCs on the GAC bed (with minimal mercury capture) and most of the mercury on the SGAC bed (with minimal VOC capture). Designing the system in this way will simplify the disposal options for both filters, since activated carbon filters with high organic concentrations (above 500 ppm) cannot be disposed of at ICDF, while activated carbon filters with high mercury concentrations would have to undergo expensive thermal retorting, off-Site, prior to their macro-encapsulation.

In addition to these activated carbon beds a smaller GAC bed is used to filter organics from the decanted supernatant stream, prior to Aquaset solidification. The weight and volume of this GAC bed is calculated to be 131 kg and 0.33 m³, respectively.

F1.2.9 Thermal Oxidation System

On the backend of the batch-ESV off-gas system is a propane-fueled thermal oxidation system. The primary purpose of the thermal oxidizer is to convert all residual carbon monoxide to carbon dioxide, so that the resulting off-gas system would qualify for MACT emission standards, if desirable. However, the thermal oxidizer also acts as an off-gas polishing system, for non-regulated noxious gases (such as hydrogen sulfide) and a back-up system for the activated carbon beds (in the event of organic breakthrough). Therefore it should not be considered similar to incineration, which burns the primary waste streams, as opposed to the treated off-gas streams from a pyrolysis system. Placing the thermal oxidation system on the downstream side of the blower allows for the benefits of thermal oxidation, without the need to manage the increased gas volume.

The fuel requirements for the thermal oxidizer are 8 L/min. Over a processing period of 144 hours, this amounts to 70 m³ of propane.

F1.2.10 Solidification of the Secondary Waste Liquids

The total volume of decanted liquid collected, prior to batch-ESV processing, is 12 m³. The total volume of condensate liquid resulting from the batch-ESV process is 5719 L. Both of these liquids are to be stabilized via Aquaset, in 55-gal drums. Aquaset is designed to solidify liquid wastes, without mixing or significant volume increase. Furthermore, indications are that the resultant product will meet LDRs for all regulatory materials (primarily) mercury that are present in the liquid, post-GAC filtration. The solidification process will involve 45 gal of liquid placed in each 55-gal drum, along with 150 lb of Aquaset. Total drum requirements for this stabilization effort are 97 drums (71 drums for the decanted liquid, and 28 drums for the collected condensate). Included in this calculation is the assumption that 315 gal of collected condensate will be stabilized with Aquaset, in the Tank V-9 shell, eliminating the need for an additional seven 55-gal drums.

F1.2.11 Solidification of the Activated Carbon Filter Housings

According to INEEL Regulatory experts, the spent activated carbon filters can be classified and disposed of as debris, provided the activated carbon contents are maintained in their respective housings. To prepare the housing for eventual macro-encapsulation as debris waste, it is necessary to cement the activated carbon within their housings, prior to shipment to ICDF (SGAC) or Envirocare (GAC). Plans are to use a micro-fine cement to accomplish this. The cemented housings include the 1.8 m³ GAC and

SGAC off-gas filter housings, and the 328L GAC housing used to filter the decanted supernatant, prior to its solidification.

F1.2.12 Excavation of the Contaminated Soil & Empty Tanks

Excavation of the V-tank area of concern will be performed using standard construction equipment (backhoes, cranes, excavators, etc.). During excavation, plans are to place a large tent structure over the dig-face, for contamination control purposes. Upon removing the tanks from the AOC, plasma-arc cutting will be used to convert the empty tanks into large pieces of metal debris.

F1.2.13 Transportation and Disposal Operations

The contaminated soil will be transported to the ICDF via 20-yd³ roll-off boxes, and dumped at the ICDF. The tank shell remnants will be cut in thirds (via plasma-arc cutting) with the respective shells loaded on trucks, for unpackaged shipment and disposal at the ICDF. The drums of solidified liquid, phosphate material, and macro-encapsulated HEPA filters will also be delivered to the ICDF, via trucks, along with cemented SGAC filter housings and large wooden boxes of secondary waste debris (PPE, nonrecoverable equipment, consumable materials). The six roll-off boxes, containing refractory material and vitrified waste will be filled with additional soil (to remove the void created from subsidence) and then placed on trucks and hauled to the ICDF, where they will be disposed of as six roll-off box packages. The cemented GAC filters will be shipped off-Site to Envirocare, via truck.

F1.2.14 Disposition Pathways

Upon completion of the batch-ESV process, the total volume of vitrified waste produced is 11.7 m³. After allowing sufficient time to cool (approximately 24 hours), the roll-off boxes containing the six vitrified monoliths will be filled with additional contaminated soil (to fill the void left by subsidence), and the entire six roll-off boxes will be transported and disposed of, intact, at the ICDF.

In addition, the batch-ESV process is expected to produce a total of 30 gal of phosphate material, on top of the six vitrified monoliths. Plans are to dispose of the phosphate layers from each vitrified monolith within each respective roll-off box. The phosphate material is expected to contain minimal concentrations of radionuclides or other hazardous material.

Secondary wastes associated with the batch-ESV process include the decanted supernatant, the collected condensate water, the off-gas GAC and SGAC housings, and the GAC filters used to remove organics from both the decanted supernatants and collected condensates. In addition, spent HEPA filters from the first-stage HEPA filter system will need to be disposed of as debris, along with all non-recoverable equipment, personal protective equipment (PPE), and consumable materials.

The liquid supernatant and collected condensate waters will be solidified with Aquaset, prior to disposal. Use of Aquaset is expected to solidify the contents of the liquid materials, without significant increases in volume. In addition, liquids containing minor quantities of solids (such as are present in the decanted supernatant and collected condensate) can be solidified using Aquaset, without the need for mixing or agitation. The Aquaset is simply added to the liquid. Vendors supplying Aquaset (i.e., Fluid Tech International) claim that 45-48 gal of liquid, placed within a 55-gal drum, can be solidified with 100-150 lb of Aquaset, with room to spare within the 55-gal drum. For purposes of calculation, an

assumption of 150 lb Aquaset being added to 45-gal of liquid within each 55-gal drum was used. Based on this calculation, the total amount of 55-gal drums needed for stabilization of the decanted supernatant and collected condensate is 97 drums, assuming that 7 drum equivalents of liquid can be solidified in Tank V-9, after it has been excavated. The total amount of Aquaset needed for stabilization is 10,500 kg. The Aquaset is expected to bind up any non-organic contaminants within the liquids, such that the stabilized waste form meets LDRs. In addition, according to mass balances prepared for this process, there should be negligible quantities mercury present in the condensate waters and decanted liquids, eliminating the need for retorting, prior to disposal. Plans are to dispose of the solidified liquids in 55-gal drums, at the ICDF.

To guarantee that the decanted liquids do not contain any hazardous organics (which could cause the waste to not meet LDRs), the decanted liquid will be filtered with GAC, prior to solidification. The amount of GAC needed for this filtration operation is based on a total saturation content of 10-wt% prior to breakthrough, and a required GAC residence time of 1 min. Both pieces of data are taken from discussions with a GAC filtration expert. In fact, data from the NWCF Mercury Removal Feasibility Study (INEEL/INT-2000-00359) indicate that GAC organic breakthrough is not experienced until it reaches an organic concentration of 14 wt%. The total calculated volume of GAC filtration needed for the decanted supernatant is 0.33 m³. Assuming a density of 0.4 kg/L, this corresponds to 131 kg. As previously stated, the lack of organic condensation in the condensate liquid eliminates the need for its GAC filtration, prior to solidification.

In contrast with the liquid GAC filters, the off-gas GAC filters and SGAC filters are designed for residence times of at least 2 seconds, each. This is based on data from INEEL GAC filtration experts indicating that greater than 99.9% organic/mercury removal can be obtained from the GAC/SGAC filters at this residence time. Although off-gas GAC/SGAC filters also have concerns over absorbent saturation, the high volume of off-gas flow used in the batch-ESV process makes the issue of residence time the dominant factor used in designing the GAC/SGAC filters. The total off-gas filters needing to be disposed of weigh 727 kg apiece (equivalent to a volume of 1.8 m³ apiece).

According to INEEL regulatory personnel, the treated GAC/SGAC filters can be cemented within their housings, then macro-encapsulated and disposed of as debris. As a result, following their uses, the GAC and SGAC filter housing will be removed from their respective operating systems, and the contents of GAC or SGAC material within each housing will be cemented internally. The cemented GAC filters will then be shipped off-Site to Envirocare, for macro-encapsulation and disposal as debris. The cemented SGAC filter housings will be sent to ICDF, for macro-encapsulation and disposal as debris. The ultimate disposition of these two filter types is based on the assumption that minimal mercury is absorbed in the GAC filters, while minimal organics are absorbed on the SGAC filters. The total quantity of concrete needed for cementation is 7680 kg.

In addition, HEPA filters from the first- and second-stage HEPA filter system will be macro-encapsulated in four 55-gal drums) and disposed of as debris, at the ICDF. The total volume of HEPA filter debris is 0.83 m³. The total volume of roll-off boxes to be disposed of at the ICDF is approximately 68.9 m³. The six roll-off boxes will also be disposed of at the ICDF. For disposition purposes, the six boxes are said to contain 11.7 m³ of primary waste (the vitrified waste forms) and 36 m³ of secondary wastes (the refractory liner material).

The total volume of secondary waste expected to be produced by the complete ESV process is 87.9 m³. This includes a disposed equipment volume of 76 m³, a solidified condensate volume of 7.1 m³, 2.2 m³ of GAC, 1.8 m³ of SGAC, and 0.8 m³ of macro-encapsulated HEPA filters. The secondary waste volume is based on the assumption that all equipment coming in contact with the tank waste and off-gas will have to be disposed of as radioactive-waste. In addition, it is assumed that there will be no consolidation of the waste by placement in containers or cutting or crushing. The actual secondary waste volume associated with this process can be substantially reduced if efforts are made to recover equipment (via D&D operations), and if actual waste can be consolidated, cut, or crushed before disposal.

All waste generated as a function of this technology will be disposed of at an approved TSDF. Table 7 provides a summary of the total volume of waste materials expected to be generated by the batch ESV process.



Appendix G

Thermal Desorption



*Pre-Conceptual Designs of Various Alternatives for the V-Tanks
Rev. 0; November 2002*

CONFIDENTIAL - UNCLASSIFIED





Appendix G

Thermal Desorption

The thermal desorption appendix currently provides the mass balance process assumptions for all alternatives, off-gas air requirements, and a detailed equipment list. The individual mass balances for each alternative (see Appendix C), estimate of propane use, estimate of electricity use, estimates of the primary and secondary waste streams, and TD bottom ranges are also presented.

Basis and Assumptions of Mass Balance Calculation for TD Treatment of V-Tank Wastes:

1. Amounts of liquid and sludge in V-tanks.
2. Major components and Contaminants for Treatment.

Note: (1) All phosphorus will be in non-volatile PO_4 form, all extra carbon will in hydrocarbon $\text{C}_{13}\text{H}_{28}$ form (hydraulic oil, with 20% mass increase vs the amount of extra carbon present in the waste mixture)

(2) SVOC

V-1: 2-methylnaphthalene

V-2: 2-methylnaphthalene, naphthalene

V-3: 2-methylnaphthalene, pyrene

V-9: 2-methylnaphthalene, naphthalene, 2, 4-dimethyl phenol, 2-methyl phenol, 4-methylphenol, di-n-butylphthalate, phenanthrene, pyrene

3. Preparation of Batch Feed Mixture (approximately 20% water requirement for optimal TD feed): Mixing of Waste Mixture (100 gal) and TAN's Soil. (See Table G-1.)

Table G-1. Preparation of batch feed mixture (approximately 20% water): mixing of waste mixture (100 gal) and TAN's soil.

Tanks	Waste Mixture Mass (100 gal, Kg)	Soil Volume* (gal)	Total Mass/Batch (Kg)
V-1	380.4	869	5309.5
V-2	380.2	839	5136.6
V-3	379.9	834	5109
V-9	414	700	4383

*Soil bulk density: 1.5 g/ml

4. Options

- (1) Collection of PCB/organic materials from TD off-gas system for off-Site treatment – with soil (20% by wt moisture).
- (2) On-site treatment of PCB/organic materials in TD system off-gas system during processing – with soil (20% by wt moisture).
- (3) Same as option 1 – without soil (wet feed).

5. TD System

- (1) For options 1 and 2 (per batch waste/soil mixture in Table G-1), one hour steady state at low temperature (95°C @ 620 mm Hg) and two hours at high temperature (300°C @ 40 mm Hg) operations. The rotary reactor has dimension of 5 ft diameter and 16 ft long. The purge rate of nitrogen gas will be 0.5 ft/sec at low temperature and 1 ft/sec at high temperature.
- (2) For option 3 (no soil added, 200 gal batch waste solution only), two hours steady state at low temperature and one hour at high temperature operations. The rotary reactor has 4 ft diameter and 8.5 ft long. The nitrogen gas purge rates are the same as above.

6. Unit Operation-option 1

Low Temperature Step (1 hour):

- (1) Rotary Kiln – at 95°C and 620 mm Hg

The following materials will vaporize to off-gas:

- 100% water, CH₃Cl, CH₃Br, TCE, PCE, 1, 2 di-chloro ethylene, methylene chloride, TCA;
 - 10% SVOC, 1,2 di-chloro benzene;
 - 20% Hg
 - All metallic species (except 20% of Hg) will remain in the dry product. All sulfur and chloride species will remain in the process residual solids. All radionuclides will remain in the residual solids; and
 - All PCBs, BEHP, hydraulic oil, and 90% SVOC, 1,2 di-chloro benzene will remain in the residual dry products. All organic material will not thermally decompose under the operated conditions in the process system.
- (2) Rotary kiln, super heater, metal filter – effluent gas included water vapor, nitrogen, organics and mercury species. Total standard volumetric flow rate is assumed through these units, although the actual volumetric flow rate change due to pressure drops and temperature change.
 - (3) Condenser – at 60°C.

The following materials will be removed from rotary reactor off-gas by condenser (as condensate):

- 0% of CH₃Cl, CH₃Br, 1, 2 di-chloro ethylene, methylene chloride;
- 20% of TCE, PCE, TCA;
- 60% Hg; and
- 99% SVOC, 1,2 di-chloro benzene.

The amount of water above its vapor pressure (at 60°C) will also condense.

Condenser gas effluent – at 60°C and 570 mm Hg.

Gas component includes water, nitrogen, organics and Hg.

- (4) HEME – at 60°C and 550 mm Hg, Heater – at 150°C and 550 mm Hg
- (5) HEPA + GAC – at 150°C and 530 mm Hg, remove all Hg, and organic (and all radionuclides)^j

High Temperature Step (2 hours):

- (1) Rotary Kiln – at 300°C and 40 mm Hg

All SVOC, hydraulic oil, and 99.9% of Hg, BEHP and PCB in the dry product from low temperature operation will vaporize (non-decomposed) to off-gas. All metallic species, sulfur and inorganic chloride species (except Hg), and radionuclides will remain the dry products

- (2) Rotary kiln, super heater, and metal filter off-gas – there is no change in the mass flow or standard volumetric flow rate, but some change of actual volumetric flow rate due to temperature change and pressure drop
- (3) Vacuum Pump – this in-line vacuum pump needs to handle high temperature (300°C) environment and maintain high vacuum on rotary kiln
- (4) Condenser liquid and gas – at 25°C and 550 mm Hg

Assume 60% of Hg, 99% of PCB, SVOC, BEHP, 1, 2 di-chloro benzene, and hydraulic oil will condense. The balance of these components will be carried out by nitrogen flow

- (5) HEME and Heater
- (6) GAC and HEPA – at 150°C and 510 mm Hg

^j If the capture of VOC at 150°C is not adequate to meet off-gas emissions requirements, a lower condensation temperature may be required in order to set the conditions (temperature and relative humidity) of the GAC influent for optimal VOC capture. The resulting effect of lowering condensation temperature is the increase of condensate water, thus increasing this particular secondary waste

All Hg, organic compounds and radionuclides (if any) in off-gas will be removed by GAC, SGAC, or HEPA filter (see earlier footnote on condenser temperature impact given for Stage 1).

7. Unit Operation-option 2

Low Temperature Step (1 hour)

Both options 1 and 2 have very similar process unit and procedure for low temperature operations. The low temperature off-gas will be fed to a thermal oxidizer to destroy the VOCs.^k After the thermal oxidizer, a wet scrubber (instead of condenser) will be used for option 2. While operating the scrubber, the scrubber solution collected can be reused to minimize the waste.

High Temperature Step (2 hours)

Except for the off-gas unit operations after thermal oxidizer, the assumptions for rotary kiln operations remain the same as option 1. The dry products from both options are exactly the same.

Thermal Oxidizer (for option 2):

The estimated inlet feed rates for low and high temperature processes to the thermal oxidizer are listed in Table G-2 and G-3.

k. Depending on the requirements of the particular thermal oxidizer, a pre-heater may be needed for the low temperature stage to allow the influent gas stream to reach a desired temperature for VOC destruction within the oxidizer.

Table G-2. Thermal oxidizer hourly feed rates – low temperature.

Chemicals	V-1	V-2	V-3	V-9
H ₂ O (Kg)	1060	1030	1020	880
TCE (g)	1.4	0.1	0	6030
PCE (g)	167	52	49	176
N ₂ (Kg)	756	756	756	756
Hg (g)	27	23	25	164
SVOC (g)	0	3	5	2
CH ₃ Cl (g)	0	0	0	23
CH ₃ Br (g)	0	0	0	43
TCA (g)	0	0	0	738
CH ₂ Cl ₂ (g)	0	0	0	5
di-chloro benzene (g)	0	0	0	6

Table G-3. Thermal oxidizer hourly feed rates – high temperature.

Chemicals	V-1	V-2	V-3	V-9
N ₂ (Kg)	62.7	62.7	62.7	62.7
Hg (g)	53	46	51	329
PCB-1260 (g)	10	6	10	32
Hydraulic Oil (Kg)	5.1	11.1	8.7	2.6
BEHP (g)	173	110	242	115
SVOC (g)	170	110	218	75
di-cl benzene (g)	0	0	0.5	26

Off-gas from low temperature operation (stage 1): needs 3773 kg/hr of air and 159 kg/hr of propane, for all four types of waste.

Off-gas from high temperature operation (stage 2): needs various amounts of air for four types of waste. Due to adequate contents of organic species in the off-gas from processing V-1, V-2, and V-3 wastes, it was calculated that extra fuels are not require to operate thermal oxidizer, and only 1.4 Kg/hr of propane is needed for waste stream from V-9. The calculated thermal oxidizers off-gas equilibrium compositions are shown in Table G-4 and G-5.

Table G-4. Equilibrium compositions of thermal oxidizer off-gas (Kmol/hr) for low temperature operations.

Chemicals	V-1	V-2	V-3	V-9
N ₂	135	135	135	136
CO ₂	5.45	5.42	5.42	5.46
H ₂ O	66.2	64.4	63.9	56.1
O ₂	14.5	14.6	14.6	14.8
Hg	1.79E-30	6.00E-30	1.00E-29	7.00E-31
HCl	3.20E-05	1.55E-04	1.15E-04	1.80E-03
Cl ₂	1.74E-03	4.35E-04	2.40E-04	6.87E-02
HgCl ₂	1.35E-04	1.15E-04	1.25E-04	2.27E-03
NO	3.00E-14	3.00E-14	3.00E-14	3.00E-14
NO ₂	1.20E-08	1.20E-08	1.20E-08	1.20E-08
HBr	0	0	0	6.40E-12
Br ₂	0	0	0	1.13E-04

Table G-5. Equilibrium compositions of thermal oxidizer off-gas (Kmol/hr) for high temperature operations.

Chemicals	V-1	V-2	V-3	V-9
Air Added (Kg/hr)	145	250	203	136
N ₂	6.37	9.37	8.04	6.12
CO ₂	0.375	0.792	0.636	0.421
H ₂ O	0.403	0.853	0.685	0.401
O ₂	0.327	0.342	0.292	0.228
Hg	1.59E-04	1.75E-04	1.62E-04	2.00E-04
HCl	4.70E-19	6.00E-19	7.00E-19	1.85E-04
Cl ₂	5.00E-31	4.00E-31	6.00E-31	6.81E-02
Hg ₂	5.00E-10	4.00E-10	4.00E-10	0
HgCl ₂	1.05E-04	5.40E-05	9.2E-05	1.64E-03
NO	9.00E-16	1.00E-15	1.00E-15	8.00E-16
NO ₂	3.20E-10	3.00E-10	2.80E-10	2.00E-10

All HCl, Cl₂, Br₂, 50% Hg, and 98% HgCl₂ from the oxidizer off-gas will be removed by the wet scrubber (assume the recycle water will be used as quench/scrubbing solution).

8. Unit Operation-option 3 (no soil)

In addition to not adding soil for waste process, the other difference between option 1 and options 3 are: (1) smaller rotary reactor (lower purge gas) for option 3, and (2) different operating time for low and high temperature steps. For option 3, it was assumed that approximately two hours for low temperature and one hour for high temperature operations would be needed to process a batch of 200 gallons waste mixture. All other process assumptions remain the same.

Equipment Lists

Equipment lists have been developed for each of the thermal desorption technology alternatives identified in this pre-conceptual design report. In section 4, each of the major components have been presented and summarized. The following lists provide additional details specific to both the primary and secondary equipment necessary to deploy this technology.

1. Alternative 1 & 3
 - 1.1 Portable Tools (drills, saws, etc.)
 - 1.2 CAT 330 Excavator
 - 1.3 CAT 950 Front-End Loader
 - 1.4 Diesel Tractor w/Flatbed (40,000 GVW)
 - 1.5 8000 lb Fork Lift
 - 1.6 CAT Grader
 - 1.7 Portable 10 ton Crane
 - 1.8 Portable Hydraulic Compactor
 - 1.9 Portable Water Truck (5,000 gallon)
 - 1.10 V-Tanks Waste Removal/Feed System (AEA)
 - 1.11 Radiological Shielding
 - 1.12 Soil Delivery System – 6 in by 10 ft screw auger with vibrating screened loading hopper
 - 1.13 Nitrogen Gas Feed System (400 gallon)
 - 1.14 Propane Storage Tank (3000 gallon)
 - 1.15 Vacuum Assisted Rotary Kiln Thermal Desorber dimensions – 5 ft in diameter by 16 ft in length. Capable of 400°C temperatures, and heated by natural gas, propane or electricity
 - 1.16 Bottoms Collection Hopper
 - 1.17 Drum Loading Station
 - 1.18 270 55-gallon drums (150 for TD residue, 110 for condensate)



-
- 1.19 10 Roll-off Containers
 - 1.20 20 Roll-off Liners
 - 1.21 Stabilization Station
 - 1.22 200 80-lb bags of Portland Cement or Aqua-set
 - 1.23 24 kW Super Heater capable of heating off-gas to 300°C, operated during both low and high temperature operations to avoid condensation of water and heavy organics
 - 1.24 Sinter Metal Filter capable of routine operations at 300°C, constructed of stainless steel, capable of removing particle sizes up to 2 microns
 - 1.25 Stokes High Vacuum Pump (Model K 612H) capable of withstanding 300°C and reducing and maintaining operating pressure at 40 mm Hg
 - 1.26 Ingersoll Rand Condenser (Model R-10-A) capable of reducing off-gas temperatures down to 25°C at 550 mm Hg
 - 1.27 Condenser Supply Tank (4000 gallon carbon steel)
 - 1.28 Low Temperature Surge Tank (4000 gallon carbon steel)
 - 1.29 High Temperature Surge Tank (4000 gallon carbon steel)
 - 1.30 High Integrity Containers (1000 gallon HDPE) for off-gas liquids
 - 1.31 Mist Eliminator (demister) capable of operating at 60°C and 550 mm Hg, and 150°C and 550 mm Hg
 - 1.32 1000 gallon carbon steel feed tank
 - 1.33 12 KW Electric Heater
 - 1.34 HEPA Filter Bank – Two sets of 3-24” x 24” HEPA filters, capable of operating at 150°C and 530 mm Hg
 - 1.35 Activated Carbon Filters – Two sets of 3 carbon filters. Each set has a granular activated carbon (GAC) filter followed by two sulfur impregnated GAC filters, and operation at 150°C and 510 mm Hg. Assume Hg loading of 10 – 15 wt % on the SGAC filters
 - 1.36 Blower (1 PSI, 262 CFM, 2 HP, Frame Size 36) capable of 300 cfm
 - 1.37 Area Monitoring System (Remote) – 1 digital camera and 2 VHS VCR’s for data recording
2. Alternative 2
- 2.1 Portable Tools (drills, saws, etc.)
 - 2.2 CAT 330 Excavator
 - 2.3 CAT 950 Front-End Loader
 - 2.4 Diesel Tractor w/Flatbed (40,000 GVW)
 - 2.5 8000 lb Fork Lift
 - 2.6 CAT Grader

-
- 2.7 Portable 10 ton Crane
 - 2.8 Portable Hydraulic Compactor
 - 2.9 Portable Water Truck (5,000 gallon)
 - 2.10 V-Tanks Waste Removal/Feed System (AEA)
 - 2.11 Soil Delivery System – 6 in by 10ft screw auger with vibrating screened loading hopper
 - 2.12 Nitrogen Gas Feed System (400 gallon)
 - 2.13 Propane Storage Tank (3000 gallon)
 - 2.14 Vacuum Assisted Rotary Kiln Thermal Desorber: dimensions – 4 ft. in diameter by 8.5 ft. in length. Capable of 400°C temperatures, and heated by natural gas, propane or electricity
 - 2.15 Bottoms Collection Hopper
 - 2.16 Drum Loading Station
 - 2.17 270 55-gallon drums (150 for TD residue, 110 for condensate)
 - 2.18 10 Roll-off Containers
 - 2.19 26 Roll-off Liners
 - 2.20 Stabilization Station
 - 2.21 200 80-lb bags of Portland Cement or Aqua-set
 - 2.22 24 kW Super Heater capable of heating off-gas to 300°C, operated during both low and high temperature operations to avoid condensation of water and heavy organics
 - 2.23 Sinter Metal Filter capable of routine operations at 300°C, constructed of stainless steel, capable of removing particle sizes up to 2 microns
 - 2.24 Stokes High Vacuum Pump (Model K 612H) capable of withstanding 300°C and reducing and maintaining operating pressure at 40 mm Hg
 - 2.25 Flameless Thermal Oxidizer. Vendor typically supplies quench, scrubber, supply tank and stack sized to support operations
 - 2.26 Quench
 - 2.27 4000-gallon quench supply tank (carbon steel or high density polyethylene storage tank). This tank will be used for both quench and scrubber operations
 - 2.28 Venturi Wet Spray Scrubber
 - 2.29 1000-gallon caustic supply tank (carbon steel or high density polyethylene storage tank)
 - 2.30 Stabilization/Amalgamation Station
 - 2.31 Mist Eliminator capable of operating at 60°C and 550 mm Hg, and 150°C and 550 mm Hg
 - 2.32 12 KW Electric Heater
 - 2.33 HEPA Filter Bank – Two sets of 3-24” x 24” HEPA filters, capable of operating at 150°C and 530 mm Hg

-
- 2.34 Activated Carbon Filters – Two sets of 3 carbon filters. Each set has a granular activated carbon (GAC) filter followed by two sulfur impregnated GAC filters, and operation at 150°C and 510 mm Hg. Assume Hg loading of 10 – 15 wt % on the SGAC filters
 - 2.35 Blower (1 PSI, 262 CFM, 2 HP, Frame Size 36) capable of 300 cfm
 - 2.36 Area Monitoring System (Remote) – 1 digital camera and 2 VHS VCR's for data recording

The following tables present the off-gas flow rates for the three alternatives.

Table G-6. TD On/Off-Site off-gas flow rates (100 gal/batch).

Tank	# of Batches	Operating Temp.	Duration (hours)	Off-gas Flow Rate (SCFH)	Gas Species (kg/hr)				
					N ₂	H ₂ O	CO ₂	O ₂	Rad. Comp.
V-1	17	low	1	3.16E+04	7.56E+02	1.68E+02			
		high	2	4.79E+03	1.55E+02				
V-2	16	low	1	3.16E+04	7.56E+02	1.68E+02			
		high	2	5.35E+03	1.73E+02				
V-3	23	low	1	3.16E+04	7.56E+02	1.68E+02			
		high	2	4.96E+03	1.66E+02				
V-9	4	low	1	3.16E+04	7.56E+02	1.68E+02			
		high	2	4.51E+03	1.46E+02				
Total (kg)					6.50E+04	1.01E+04	0.00E+00	0.00E+00	trace
Total (scfh)				2.49E+06					

Table G-7. TD On-Site off-gas flow rates (100 gal/batch).

Tank	# of Batches	Operating Temp.	Duration (hours)	Off-gas Flow Rate (SCFH)	Gas Species (kg/hr)				
					N ₂	H ₂ O	CO ₂	O ₂	Rad. Comp.
V-1	17	low	1	1.80E+05	3.78E+03	1.01E+03	2.40E+02	4.64E+02	
		high	2	8.49E+03	1.78E+02	5.01E+01	1.63E+01	1.05E+01	
V-2	16	low	1	1.80E+05	3.78E+03	1.01E+03	2.38E+02	4.67E+02	
		high	2	1.35E+04	2.62E+02	7.82E+01	3.46E+01	1.09E+01	
V-3	23	low	1	1.80E+05	3.78E+03	9.80E+02	2.38E+02	4.67E+02	
		high	2	1.05E+04	2.25E+02	5.70E+01	2.78E+01	9.34E+00	
V-9	4	low	1	1.80E+05	3.78E+03	9.82E+02	2.40E+02	4.74E+02	
		high	2	7.91E+03	1.71E+02	4.30E+01	1.25E+01	1.15E+01	
Total (kg)					2.53E+05	6.70E+04	1.74E+04	2.92E+04	trace
Total (scfh)				1.21E+07					

Table G-8 TD Off-Site off-gas flow rates (200 gal/batch).

Tank	# of Batches	Operating Temp.	Duration (hours)	Off-gas Flow Rate (SCFH)	Gas Species (kg/hr)				
					N ₂	H ₂ O	CO ₂	O ₂	Rad. Comp.
V-1	9	low	2	2.03E+04	4.86E+02	1.06E+02			
		high	1	5.68E+03	1.84E+02				
V-2	8	low	2	2.03E+04	4.86E+02	1.06E+02			
		high	1	6.98E+03	2.26E+02				
V-3	12	low	2	2.03E+04	4.86E+02	1.06E+02			
		high	1	6.14E+03	1.99E+02				
V-9	2	low	2	2.03E+04	4.86E+02	1.06E+02			
		high	1	3.64E+03	1.18E+02				
Total (kg)					3.62E+04	6.57E+03	0.00E+00	0.00E+00	trace
Total (scfh)				1.45E+06					

Tables G-9 through G-14 provide data on propane and electricity usage, primary and secondary waste , bottoms ranges, and low temperature operating parameters for SVOC desorption.

Table 11. Propane

Tank #	Waste Vol (L)	Waste Vol (Gal)	# of Batch's	Option #	Operation Mode (Low & High T)	Hours of Operation	Propane Usage Rate (Btu/hr)	Total Propane Used (Btu)	Total Propane /Option /Tank (Btu)	Total Propane For All Tanks /Option (Btu)	Total Propane For All Tanks /Option (Gallons)
1	6374	1686	17	1	Low	1	7.69E+06	1.31E+08	1.75E+08	6.18E+08	6896
					High	2	1.3 E+6	4.42E+07			
					Low	1	7.69E+06	1.31E+08	1.75E+08		
					High	2	1.3 E+6	4.42E+07			
				3	Low	2	2.31E+06	4.16E+07	4.22E+07	1.45E+08	1620
					High	1	6.24E+04	5.62E+05			
					Low	1	7.69E+06	1.23E+08	1.65E+08		
					High	2	1.3 E+6	4.16E+07			
2	6041	1598	16	1	Low	1	7.69E+06	1.23E+08	1.65E+08	6.18E+08	6896
					High	2	1.3 E+6	4.16E+07			
					Low	1	7.69E+06	1.23E+08	1.65E+08		
					High	2	1.3 E+6	4.16E+07			
				3	Low	2	2.31E+06	3.70E+07	3.75E+07	1.45E+08	1620
					High	1	6.24E+04	5.00E+05			
					Low	1	7.69E+06	1.77E+08	2.37E+08		
					High	2	1.3 E+6	5.98E+07			
3	8755	2316	23	1	Low	1	7.69E+06	1.77E+08	2.37E+08	6.18E+08	6896
					High	2	1.3 E+6	5.98E+07			
					Low	1	7.69E+06	1.77E+08	2.37E+08		
					High	2	1.3 E+6	5.98E+07			
				3	Low	2	2.31E+06	5.54E+07	5.62E+07	1.45E+08	1620
					High	1	6.24E+04	7.49E+05			
					Low	1	7.69E+06	3.10E+07	4.14E+07		
					High	2	1.3 E+6	1.04E+07			
9	1211	320	4	1	Low	1	7.69E+06	3.10E+07	4.14E+07	6.18E+08	6896
					High	2	1.3 E+6	1.04E+07			
					Low	1	7.69E+06	3.10E+07	4.14E+07		
					High	2	1.3 E+6	1.04E+07			
				3	Low	2	2.31E+06	9.24E+06	9.37E+06	1.45E+08	1620
					High	1	6.24E+04	1.25E+05			
					Low	1	7.69E+06	3.10E+07	4.14E+07		
					High	2	1.3 E+6	1.04E+07			

Assumptions:

- Heat transfer efficiency is 35% for low temperature operations
- Heat transfer efficiency is 25% for high temperature operations
- There are 89670 Btu/gal liquid propane.

Table 12. Electricity

Tank #	Option	Temperature Operation Mode	Number of Batch's	Super heater (Btu/hr)	Super Heater (KW)	Total Super Heater Electricity (KW)	Re-Heater (Btu/hr)	Re-Heater (KW)	Total Super Heater Electricity (KW)	Total Power Option / Tank (KW)	Total Power / Option (KW)
V-1	1	Low	17	4.02E+04	2.00E+02	2.08E+02	1.08E+05	5.38E+02	5.38E+02	7.46E+02	2.87E+03
		High	17	1.49E+03	7.42E+00	2.08E+02	1.08E+05	5.38E+02	5.38E+02	7.46E+02	2.87E+03
V-1	2	Low	17	4.02E+04	2.00E+02	2.08E+02	5.65E+05	2.82E+03	2.91E+03	3.12E+03	8.11E+03
		High	17	1.49E+03	7.42E+00	2.08E+02	1.93E+04	9.62E+01	2.91E+03	3.12E+03	8.11E+03
V-1	3	Low	9	1.68E+04	4.43E+01	4.43E+01	5.63E+04	1.49E+02	1.49E+02	1.97E+02	7.43E+02
		High	9	1.68E+03	4.43E+00	4.43E+00	5.63E+04	1.49E+02	1.49E+02	1.97E+02	7.43E+02
V-2	1	Low	16	4.02E+04	1.89E+02	1.95E+02	1.08E+05	5.06E+02	5.06E+02	7.02E+02	2.87E+03
		High	16	1.49E+03	6.99E+00	1.95E+02	1.08E+05	5.06E+02	5.06E+02	7.02E+02	2.87E+03
V-2	2	Low	16	4.02E+04	1.89E+02	1.95E+02	5.65E+05	2.65E+03	2.74E+03	2.94E+03	8.11E+03
		High	16	1.49E+03	6.99E+00	1.95E+02	1.93E+04	9.05E+01	2.74E+03	2.94E+03	8.11E+03
V-2	3	Low	8	1.68E+04	3.94E+01	4.33E+01	5.63E+04	1.32E+02	1.32E+02	1.75E+02	7.43E+02
		High	8	1.68E+03	3.94E+00	4.33E+01	5.63E+04	1.32E+02	1.32E+02	1.75E+02	7.43E+02
V-3	1	Low	23	5.03E+04	3.39E+02	3.51E+02	1.35E+05	9.10E+02	9.10E+02	1.26E+03	3.29E+03
		High	23	1.86E+03	1.26E+01	3.51E+02	1.35E+05	9.10E+02	9.10E+02	1.26E+03	3.29E+03
V-3	2	Low	23	5.03E+04	3.39E+02	3.51E+02	1.35E+05	9.10E+02	9.10E+02	1.26E+03	3.29E+03
		High	23	1.86E+03	1.26E+01	3.51E+02	1.16E+04	7.85E+01	9.10E+02	1.26E+03	3.29E+03
V-3	3	Low	12	2.10E+04	7.39E+01	8.12E+01	7.04E+04	2.48E+02	2.48E+02	3.29E+02	1.61E+02
		High	12	2.10E+03	7.39E+00	8.12E+01	7.04E+04	2.48E+02	2.48E+02	3.29E+02	1.61E+02
V-9	1	Low	4	3.53E+04	4.14E+01	4.30E+01	1.01E+05	1.18E+02	1.18E+02	1.61E+02	7.43E+02
		High	4	1.37E+03	1.61E+00	4.30E+01	1.01E+05	1.18E+02	1.18E+02	1.61E+02	7.43E+02
V-9	2	Low	4	3.53E+04	4.14E+01	4.30E+01	5.59E+05	6.55E+02	6.77E+02	7.20E+02	1.88E+03
		High	4	1.37E+03	1.61E+00	4.30E+01	1.85E+04	2.17E+01	6.77E+02	7.20E+02	1.88E+03
V-9	3	Low	2	1.56E+04	9.14E+00	9.86E+00	5.46E+04	3.20E+01	3.20E+01	4.19E+01	1.61E+02
		High	2	1.22E+03	7.15E-01	9.86E+00	5.46E+04	3.20E+01	3.20E+01	4.19E+01	1.61E+02

TD option: Off-Gas Heating and Cooling Requirements

Assumptions:

- Super heater: off-gas temperature increase 15°C for low temperature mode and 20°C for high temperature mode
- Condenser: off-gas temperature decrease from 100 to 60°C for low temperature mode
- Re-heater: off-gas temperature increase from 60° to 150°C for low temperature mode
- It will require the same Btu/hr to treat Tank V-2 as required to treat Tank V-1
- The electrical power required for Option 1 will be used for cost estimating purposes
- Total electrical power for treatment of all tank waste in Option 1 is 2870 KW
- Total electrical power for treatment of all tank waste in Option 2 is 8110 KW
- Total electrical power for treatment of all tank waste in Option 3 is 743 KW

Table 13. Secondary Waste

Equipment	Dimensions	Quantity (ft3)	Option 1	Total (ft3)	Option 2	Total (ft3)	Option 3	Total (ft3)
TD Vessel	5' x 15'	256	1.0	256.0	1.0	256.0		
TD Vessel (3 only)	3' x 15'	98					1.0	98.0
Hopper (Sized)	360 gallons	46	1.0	46.0	1.0	46.0	1.0	46.0
Super Heater	5' x 2' x 1'	10	1.0	10.0	1.0	10.0	1.0	10.0
Metal Filter	2' x 3' x 4'	24	1.0	24.0	1.0	24.0	1.0	24.0
Vacuum Pump	4' x 4' x 7'	112	1.0	112.0	1.0	112.0	1.0	112.0
Condenser	6' x 8' x 3'	144	1.0	144.0			1.0	144.0
Thermal Oxidizer	12' x 12' x 6'	864			1.0	864.0		
Quench								
Venturi Scrubber								
Mist Eliminator	2' x 3' x 1'	6	1.0	6.0	1.0	6.0	1.0	6.0
Heater	5' x 2' x 1'	10	1.0	10.0	1.0	10.0	1.0	10.0
Blower	1.5' x 2.5' x 2'	7.5	1.0	7.5	1.0	7.5	1.0	7.5
AEA		1240	1.0	1240.0	1.0	1240.0	1.0	1240.0
Misc. Piping/Ducting		20	1.0	20.0	1.0	20.0	1.0	20.0
Equipment Totals				1875.5		2595.5		1717.5
(80%) of Eq Totals				1500.4		2076.4		1374.0
4000 Gal Tank	4000 gallons	512	1.0	512.0	1.0	512.0	1.0	512.0
1000 Gal HIC	1000 gallons	128			2.0	256.0		
Condenser Water (1)	13,300 gallons	1705	1.0	1705.0				
Condenser Water (3)	3,620 gallons	464					1.0	464.0
Scrubber Solution (2) - Treated	4,558 gallons	584			1.0	584.0		
GAC		10	88.0	880.0			88.0	880.0
S-GAC		10	4.0	40.0	20.0	200.0	4.0	40.0
HEPA	3 (2' x 2' x 2')	24	1.0	24.0	1.0	24.0	1.0	24.0
Soil Feed System	2' x 2' x 10'	40	1.0	40.0	1.0	40.0		
Grand Total (ft3)				4701.4		3692.4		3294.0
Grand Total (m3)				133.2		104.6		93.3

Notes:

1. Thermal Oxidizer assembly includes both the quench and scrubber assemblies
2. The total volume of secondary waste from equipment is assumed to be 80% of calculated value.

Table 14. Primary Waste

Components	Dimensions	Quantity (ft3)	Option 1	Total (ft3)	Option 2	Total (ft3)	Option 3	Total (ft3)
V-Tank #1	10' x 19.5'	55.1	1.0	55.1	1.0	55.1	1.0	55.1
V-Tank #2	10' x 19.5'	55.1	1.0	55.1	1.0	55.1	1.0	55.1
V-Tank #3	10' x 19.5'	55.1	1.0	55.1	1.0	55.1	1.0	55.1
V-Tank #9	3.5' x 7'	3	1.0	3.0	1.0	3.0	1.0	3.0
Piping		3	1.0	3.0	1.0	3.0	1.0	3.0
Bottoms	6708 ft3 of soil in 1 & 2	1	7162.0	7162.0	7162.0	7162.0	84.2	84.2
Soil	(3122 yd3)	1	77592.0	77592.0	77592.0	77592.0	84300.0	84300.0
Grand Total (ft3)				84925.3		84925.3		84555.5
Grand Total (m3)				2405.8		2405.8		2395.3

Table 15. TD Bottoms Ranges

	Option 1			Option 2			Option 3		
	95% UCL	Mean	95% LCL	95% UCL	Mean	95% LCL	95% UCL	Mean	95% LCL
Cd (mg/kg)	2.81E+00	1.88E+00	9.45E-01	2.81E+00	1.88E+00	9.45E-01	2.44E+02	1.63E+02	1.22E+02
Pb (mg/kg)	4.38E+01	2.62E+01	1.18E+01	4.38E+01	2.62E+01	1.18E+01	3.81E+03	2.27E+03	1.03E+03
Hg (mk/kg)	3.18E-02	1.93E-02	8.28E-03	3.18E-02	1.93E-02	8.28E-03	2.77E+00	1.68E+00	7.20E-01
PCB (ppm)	4.87E-03	3.44E-03	2.00E-03	4.87E-03	3.44E-03	2.00E-03	4.37E-01	3.07E-01	1.78E-01
TCE/PCE (p)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cs-137 (nCi)	2.72E+02	1.89E+02	3.41E+01	2.72E+02	1.89E+02	3.41E+01	2.39E+04	1.64E+04	9.04E+03
TRU (nCi/g)	1.26E+00	8.16E-01	5.17E-01	1.26E+00	8.16E-01	5.17E-01	1.11E+02	7.09E+01	4.03E+01

Table 16 illustrates the low temperatures required for SVOC desorption at 40 mm Hg.

Individual Constituents	VAPOR PRESSURES						
	Temperature (Deg C)						
	1mm	10mm	40mm	100mm	400mm	760mm	Melting Point (MP)
Chloromethane		-92.4	-76	-63	-38	-24	-97.7
Vinyl Chloride	-105.6	-83.7	-66.8	-53.2	-28	-13.8	-153.7
Bromomethane	-96.3	-72.8	-54.2	-39.4	-11.9	3.6	-93
Methylene chloride	-70	-43.3	-22.3	-6.3	24.1	40.7	-96.7
1,1,1-Trichloroethane	-52	-21.9	1.6	20	54.6	74.1	-30.6
Trichloroethylene (TCE)	-43.8	-12.4	11.9	31.4	67	86.7	-73
Water (H2O)	-17.3	11.3	34.1	51.6	83	100	0
Tetrachloroethylene (PCE)	-20.6	13.8	40.1	61.3	100	120.8	-19
1,2-Dichlorobenzene	20	59.1	89.4	112.9	155.8	179	-17.6
Phenol	40.1	73.8	100.1	121.4	160	181.9	40.6
2-Methylphenol	38.2	76.7	105.8	127.4	168.4	190.8	30.8
4-Methylphenol	53	88.6	117.7	140	179.4	201.8	35.5
2,4-Dimethylphenol	51.8	91.3	121.5	143	184.2	211.5	25.5
Napthelene	52.6	85.8	119.3	145.5	193.2	217.9	80.2
2-Methylnaphthylene						341.1	34.6
Mercury (Hg)	126	184	228	261	323	357	-39
bis(2-ethylhexyl) Phthalate	<200			>300		386.9	-50
PCBs (Archlor 1260)	193	251.4	295	328.4	387.9	420	
Cesium (Cs)	279	375	449	509	624	690	28.5
Cadmium (Cd)	394	484	553	611	711	765	321
Strontium (Sr)		898	1018	1111	1285	1384	800
Thallium	825	983	1103	1196	1364	1457	303.5
Antimony	886	1033	1141	1223	1364	1440	631
Europium (Eu)						1597	822
Barium		1049	1195	1301	1518	1638	850
Lead (Pb)	973	1162	1309	1421	1630	1744	328
Silver (Ag)	1357	1575	1743	1865	2090	2212	960.5
Chromium (Cr)	1616	1845	2013	2139	2361	2482	1615
Nickel (Ni)	1810	2057	2234	2364	2603	2732	1452
Beryllium (Be)	1582					2970	1278
Americium (Am)						2607	994
Plutonium (Pu)						3232	641
Uranium (U)						3818	1132
Neptunium (Np)						3902	640
Curium (Cm)							1340



Appendix H

Chemical Oxidation/Stabilization Detailed Descriptions



Pre-Conceptual Designs of Various Alternatives for the V-Tanks
Rev. 0; November 2002



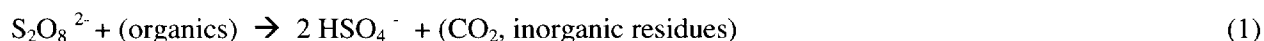


H1. CHEMICAL OXIDATION/STABILIZATION DETAILED DESCRIPTIONS

H1.1 Further Discussion of CO/S

Oxidative processes, although they can be enhanced by conditions like pH adjustment and elevated temperature or pressure, can be conducted in a tank at ambient conditions and allowed to react with simple mixing (Shaw, 1998). The three most powerful oxidants in order of their oxidative potential are fluoride, ozone, and peroxydisulfate with oxidative potentials of 2.87 V, 2.07V, and 2.05V respectively. Fluoride, although extremely powerful, is also highly toxic, posing potential worker hazards. Ozone, only marginally more powerful in terms of oxidizing potential than peroxydisulfate, is relatively difficult to generate. Peroxydisulfate, typically in the form of sodium or ammonium salt, is relatively stable at room temperature, easily obtained and mixed, and less toxic.

Chemical oxidation with the peroxydisulfate ion is an ambient pressure, non-thermal process applicable to the destruction of virtually all solid or liquid organics, including: chlorosolvents, oils and greases, detergents, organic-contaminated soils or sludges, explosives, chemical and biological warfare agents, and PCBs (Balazs et al., 1998). The net waste treatment reaction is:



Although the oxidative potential of the peroxydisulfate ion is high enough to oxidize nearly any organic substrate, carbon tetrachloride (not detected in V-tank wastes) is not oxidized in the process.

While many oxidants exhibit a redox potential capable of broad-spectrum organic oxidation, peroxydisulfate uniquely combines a high oxidative potential with a rapid, nucleophilic charge-transfer capability. Oxidation occurs principally through the formation of the sulfate radical anion ($\text{SO}_4^{\cdot-}$), following mild thermal (i.e., 70 – 100°C) or UV activation of peroxydisulfate solutions as:



The subsequent reaction of the sulfate free radical with organics and with water results in a cascade of active oxidants including organic free radical fragments and hydroxyl free radicals. The decomposition of the peroxydisulfate produces a number of intermediate oxidizers including peroxymonosulfate, hydrogen peroxide, and nascent oxygen. Such reactions typically achieve a Destruction and Removal Efficiency (DRE) in excess of 99% (Table J-1) for typical chloro-solvents (DOE 1998).

Table H-1. Typical DREs of selected chloro-solvents using peroxydisulfate oxidation.

Chloro-solvent	Extent of oxidation after 1 hour
Perchloroethylene	0.991
Trichloroethylene	0.996
Methylene chloride	0.991
Perchloroethylene/chloroform mixtures (50%)	0.991

These results compare favorably to test results (see Table J-2) obtained by Richardson et al. (1998) on actual V-tank wastes using Biochemical Oxidation System (BOS) and Palladium/Iron Bimetallic (PIB) oxidants Table J-2 (Richardson et al., 1998).

Table H-2. DREs for PCE & TCE in actual V-tank Wastes Using Biochemical Oxidation System and Palladium/Iron Bimetallic at various oxidant loadings.

Chloro-solvent	Oxidant	Extent of oxidation	Stoichiometric multiple
Perchloroethylene	BOS	0.9929	1x
Trichloroethylene	BOS	0.9907	1x
Perchloroethylene	PIB	0.9409	4x
Trichloroethylene	PIB	0.9944	4x

Such high efficiencies (i.e., >99%) will be required for trichloroethylene due to its relatively large concentration in Tank V-9. If future treatability studies determine these efficiencies are difficult to attain, the TCE (boiling point 87°C) can easily be desorbed at expected process temperatures (i.e., 70–100°C).

Although PCBs are stable and often limit the ability of any destruction technology to meet regulatory levels, the relatively low concentration of Arochlor 1260 in the V-tank waste will require a minimal DRE. It is assumed that this minimal DRE can be easily achieved through the use of peroxydisulfate. This assumption appears reasonable given the high DREs measured by Richardson et al. who report DREs for Arochlor 1260 to be 0.9273 and 0.8520 for BOS and PIB respectively.

Perhaps the most troublesome contaminant in the V-tank waste in terms of ability to achieve regulatory compliance will be bis (2-ethylhexyl) phthalate. Due to its relatively high concentration in the V-tank waste (i.e., approximately 1.8 wt%) it will require a DRE of approximately 90% to meet the regulatory limit (i.e., 28 ppm) in the final grouted waste form. Although no direct data is currently available on the DRE of bis (2-ethylhexyl) phthalate, it is assumed a 90% DRE is achievable. This assumption is based on a comparison of the molecular structure of the bis (2-ethylhexyl) phthalate molecule and its lack of stabilizing halide atoms, to the halide-rich Arochlor 1260, whose DRE in the V-tank waste approaches 90% (Richardson et al., 1998). Future treatability studies are anticipated to verify this key assumption.

The DREs reported above are likely a lower limit of the potential for destruction given that the experiments they are based on were run for a finite time with a finite mass of oxidant. During actual chemical oxidation processing of the V-tank waste, process conditions can be controlled allowing addition of excess oxidant, operating temperature increases (up to 100°C), and batch processing residence times can be increased as necessary to achieve regulatory compliance for the final waste.

Preliminary studies to support the application of chemical oxidation to the V-tank waste employed the use of non-catalytic oxidation. The oxidative process normally operates at 70–100°C; however, the radical generating process may be accelerated at lower temperatures (i.e., 20–50°C) through the use of a catalyst such as metallic platinum, or with dissolved iron or copper ion catalysts. Dissolved silver ion can be used in cases where chloride ion concentrations are small, but will precipitate as AgCl in high

concentrations of chloride ion resulting in the removal of the active catalyst (Balazs, 1998). Future treatability studies will evaluate whether the use of catalytic oxidation, to reduce operating temperatures and increase efficiency, is necessary or preferable for V-tank waste treatment.

The presence of chloride in the V-tank waste also raises tank corrosion concerns. There are several approaches to mitigating the effects of chloride induced corrosion processes (e.g. pitting), if it becomes necessary. The processing time in each tank is on the order of days, so no actions may be necessary. Reducing the reaction temperature by catalysis will reduce corrosion. Mercury can bind chloride reducing its corrosion potential to the extent it is present. The addition of nitrates or other chemical additives and/or impressing an electrical current to protect the tank galvanically could be considered.

H1.2 Grouting

The proposed grout formula consists of approximately 1.5 g of solids per milliliter of waste slurry with the solids consisting of 0.75 gms Type II cement, 0.52 gms blast furnace slag, and 0.23 gms silica fume. This formula has been optimized for mercury and other heavy metal stabilization/fixation (Richardson, et al., 1998) and has been shown to achieve TCLP requirements established in 40 CFR 261.24 for the actual V-tank waste.

H2. IN SITU CHEMICAL OXIDATION/STABILIZATION

Table H-3. In situ equipment list.

#	Item	Qty	Capacity	Throughput	Suggested Manufacturer
1	AEA Mixer	1	TBD	TBD	AEA
2	Heater Bundles	3	100 KW ea.	NA	Omega; Chromolox; Watlow
3	NaOH Feed/Make-up Tank w/agitator	1	50 gal	NA	TBD
4	NaOH Pump	1	NA	5 L/min	TBD
5	Sodium persulfate Feed/Make-up Tank w/agitator	1	1000 gal	NA	TBD
6	Sodium persulfate Pump	1	NA	10 L/min	TBD
7	Instrument Bundle (temp, pH, CO ₂ (g), air pressure, liquid volume)	3	TBD	TBD	TBD
8	Multi-Port Injection (MPI) Grouting System	3	TBD	TBD	Ground Environmental Services (ORNL/TM-2000/8)
E	Off-Gas Condenser	1	1000 BTU/min	TBD	TBD
F	Off-Gas Demister	1	TBD	TBD	TBD

Table H-3. (continued).

#	Item	Qty	Capacity	Throughput	Suggested Manufacturer
G	Off-Gas Reheater	1	1 KW	TBD	TBD
H	Sulfur Impregnated Granular Activated Carbon Canister	1	110 gal.	TBD	TBD
I	HEPA Filter	1	TBD	TBD	TBD
J	Off-Gas Blower	1	NA	100 cfm	TBD
15	Solid Sodium Hydroxide	Kg	85	TBD	TBD
16	Solid Sodium Persulfate	Kg	3020	TBD	TBD
17	Dry Grout	Kg	84030	TBD	TBD
18	55 gallon drums	375	TBD	TBD	TBD

The following items provide more information on selected items above.

3. 50 gal sodium hydroxide tank size is based on being able to use one tank to adequately supply caustic for the entire process (i.e. three batches)
4. 5 L/min sodium hydroxide pump size is based on the first pH adjust in Tank V-3 being approximately 35 L times a 1.5 safety factor yielding approximately 50 L which would be input into the reaction tank in 5 minutes (i.e., 5 L/min)
5. 1000 gal. Persulfate feed tank based on providing enough oxidant (i.e., 40% [29 w% solution] of initial waste volume for Tank V-3) to oxidize entire batch
6. 10 L/min sodium persulfate feedrate based on assuming a maximum one-month (i.e., 30 day) total processing time. Thus each batch is assumed to take 10 days to complete. Assuming the first 5 days of this 10 day period is reserved for the first aliquot of reactant and that the persulfate feed time should not be any longer than 5% of the aliquot reaction time (in this case 5 days) we get 20% of the initial waste volume (29w% solution of sodium persulfate) in Tank V-3 occurring within a time period of 360 min. (i.e., 5 days x 0.05 x 24 hrs/day x 60 min/hr) or a rate of 7.3 L/min (i.e., 2622 L/360 min). 7.3 L/min multiplied by a safety factor of 1.5 yields approximately 10 L/min
- H. 110 gal GAC volume is based on an off-gas flow rate of 100 cfm (i.e., 1.66 ft³/sec) multiplied by a required residence time of 7.5 sec to get 12.5 ft³ multiplied by an engineering safety factor of 1.2 to get approximately 15 ft³ or approximately 110 gallons or two 55 gallons drums of GAC
- J. 100 cfm off-gas throughput is based on the maximum feed rate of sodium persulfate at 10 L/min. A 29w% solution of sodium persulfate at a density of 1.14 g/ml and a flow-rate of 10 L/min has a molar flow rate of 17.2 moles/min S₂O₈. One mole of S₂O₈ produces two moles of sulfate radical ion (SRA). Assuming one mole of SRA results in the creation of one mole of carbon dioxide gas we can estimate the production rate of CO₂ at 34.4 mol/min. At a temperature of 80C and at 0.84 atmospheres this results in a CO₂ production rate of 42 cfm. Multiplying this by a safety factor of

2.0 yields approximately 84 cfm when added to a background air “bleed” rate of 15 cfm results in a maximum off-gas flow rate of approximately 100 cfm.

H3. EX SITU CHEMICAL OXIDATION/STABILIZATION

Table H-4. Ex situ equipment list.

#	Item	Qty	Capacity	Throughput	Suggested Manufacturer
1	AEA Mixer	1	TBD	TBD	AEA
C	Above ground Reaction Tank w/agitator	1	3500 gal	TBD	TBD
3	Instrument Bundle (temp, pH, CO ₂ (g), air pressure, liquid volume)	3	TBD	TBD	TBD
4	NaOH Feed/Make-up Tank w/agitator	1	50 gal	NA	TBD
5	NaOH Pump	1	NA	5 L/min	TBD
6	Sodium Persulfate Feed/Make-up Tank w/agitator	1	1000 gal	NA	TBD
7	Sodium persulfate Pump	1	NA	10 L/min	TBD
E	Grout Mixer/Extruder	1	TBD	5 gal/min	TBD
9	30' x 60' x 15' high drum process/handling/staging enclosure (negative air)	1	NA	NA	TBD
J	Off-Gas Condenser	1	1000 BTU/min	TBD	TBD
K	Off-Gas Demister	1	TBD	TBD	TBD
L	Off-Gas Reheater	1	1 KW	TBD	TBD
M	Sulfur Impregnated Granular Activated Carbon Canister	1	110 gal.	TBD	TBD
N	HEPA Filter	2	TBD	TBD	TBD
O	Off-Gas Blower	2	NA	100 cfm	TBD
16	Solid Sodium Hydroxide	Kg	85	TBD	TBD
17	Solid Sodium Persulfate	Kg	3020	TBD	TBD
I	Dry Grout	Kg	84030	TBD	TBD
G	55 gallon steel drums	375	TBD	TBD	TBD



The following items provide more information on selected items above.

4. 50 gal sodium hydroxide tank size is based on being able to use one tank to adequately supply caustic for the entire process (i.e. three batches)
5. 5 L/min sodium hydroxide pump size is based on the first pH adjust in Tank V-3 being approximately 35 L times a 1.5 safety factor yielding approximately 50 L which would be input into the reaction tank in 5 minutes (i.e., 5 L/min)
6. 1000 gal. Persulfate feed tank based on providing enough oxidant (i.e., 40% [29 w% solution] of initial waste volume for Tank V-3) to oxidize entire batch.
7. 10 L/min sodium persulfate feedrate based on assuming a maximum one-month (i.e., 30 day) total processing time. Thus each batch is assumed to take 10 days to complete. Assuming the first 5 days of this 10 day period is reserved for the first aliquot of reactant and that the persulfate feed time should not be any longer than 5% of the aliquot reaction time (in this case 5 days) we get 20% of the initial waste volume (29w% solution of sodium persulfate) in Tank V-3 occurring within a time period of 360 min. (i.e., 5 days x 0.05 x 24 hrs/day x 60 min/hr) or a rate of 7.3 L/min (i.e., 2622 L/360 min). 7.3 L/min multiplied by a safety factor of 1.5 yields approximately 10 L/min
- M. 110 gal GAC volume is based on an off-gas flow rate of 100 cfm (i.e., 1.66 ft³/sec) multiplied by a required residence time of 7.5 sec to get 12.5 ft³ multiplied by an engineering safety factor of 1.2 to get approximately 15 ft³ or approximately 110 gallons or two 55 gallons drums of GAC
- O. 100 cfm off-gas throughput is based on the maximum feed rate of sodium persulfate at 10 L/min. A 29w% solution of sodium persulfate at a density of 1.14 g/ml and a flow-rate of 10 L/min has a molar flow rate of 17.2 moles/min S₂O₈. One mole of S₂O₈ produces two moles of sulfate radical ion (SRA). Assuming one mole of SRA results in the creation of one mole of carbon dioxide gas we can estimate the production rate of CO₂ at 34.4 mol/min. At a temperature of 80C and at 0.84 atmospheres this results in a CO₂ production rate of 42 cfm. Multiplying this by a safety factor of 2.0 yields approximately 84 cfm when added to a background air “bleed” rate of 15 cfm results in a maximum off-gas flow rate of approximately 100 cfm.